AD-A041 124 WAYNE STATE UNIV DETROIT MICH DEPT OF GEOLOGY F/G 13/2
GEOLOGIC CONSIDERATIONS F)F SOUTHEASTERN MICHIGAN WASTEWATER MA--ETC(U)
FEB 73 A J MOZOLA DACW35-72-C-0008
UNCLASSIFIED NL

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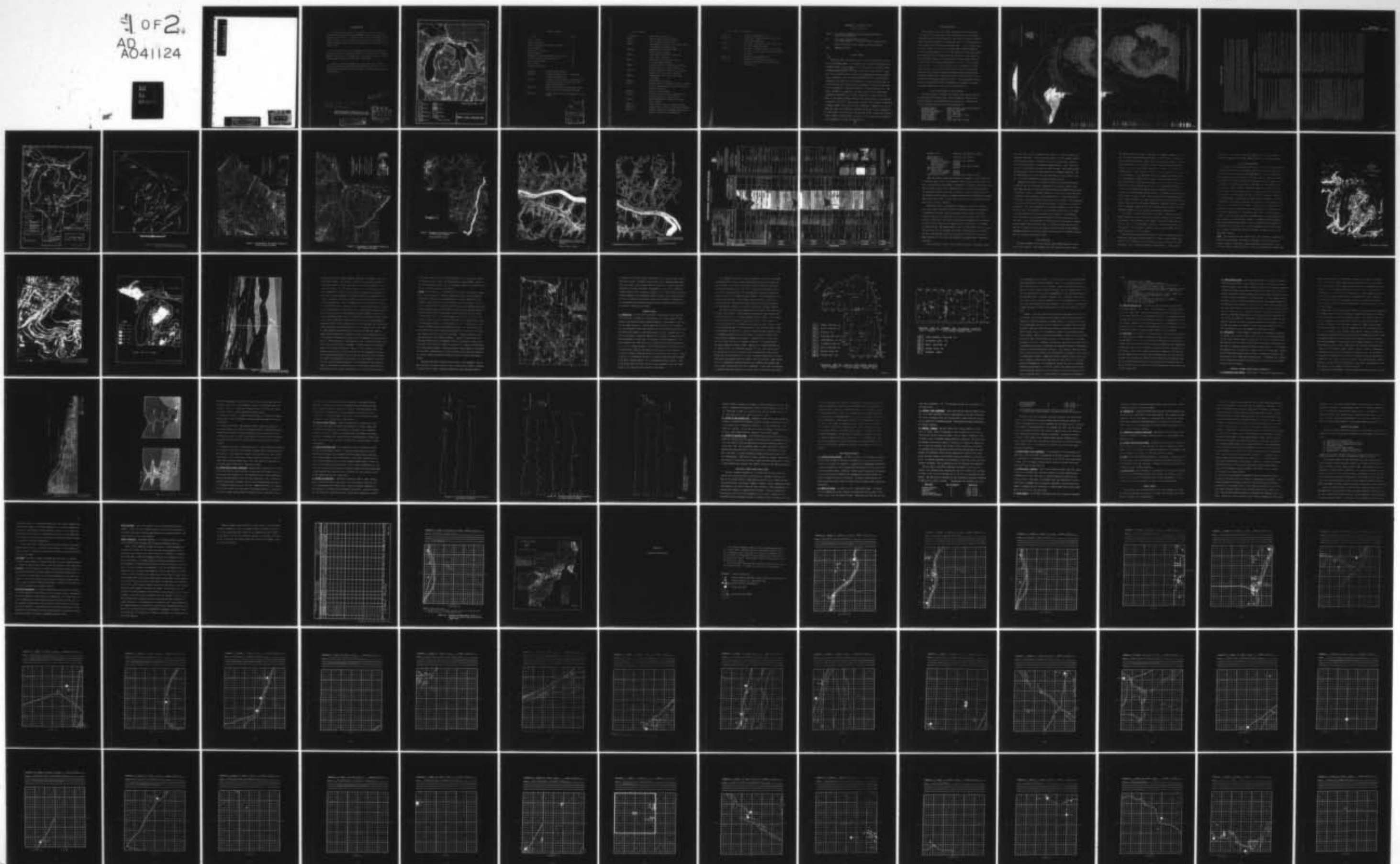


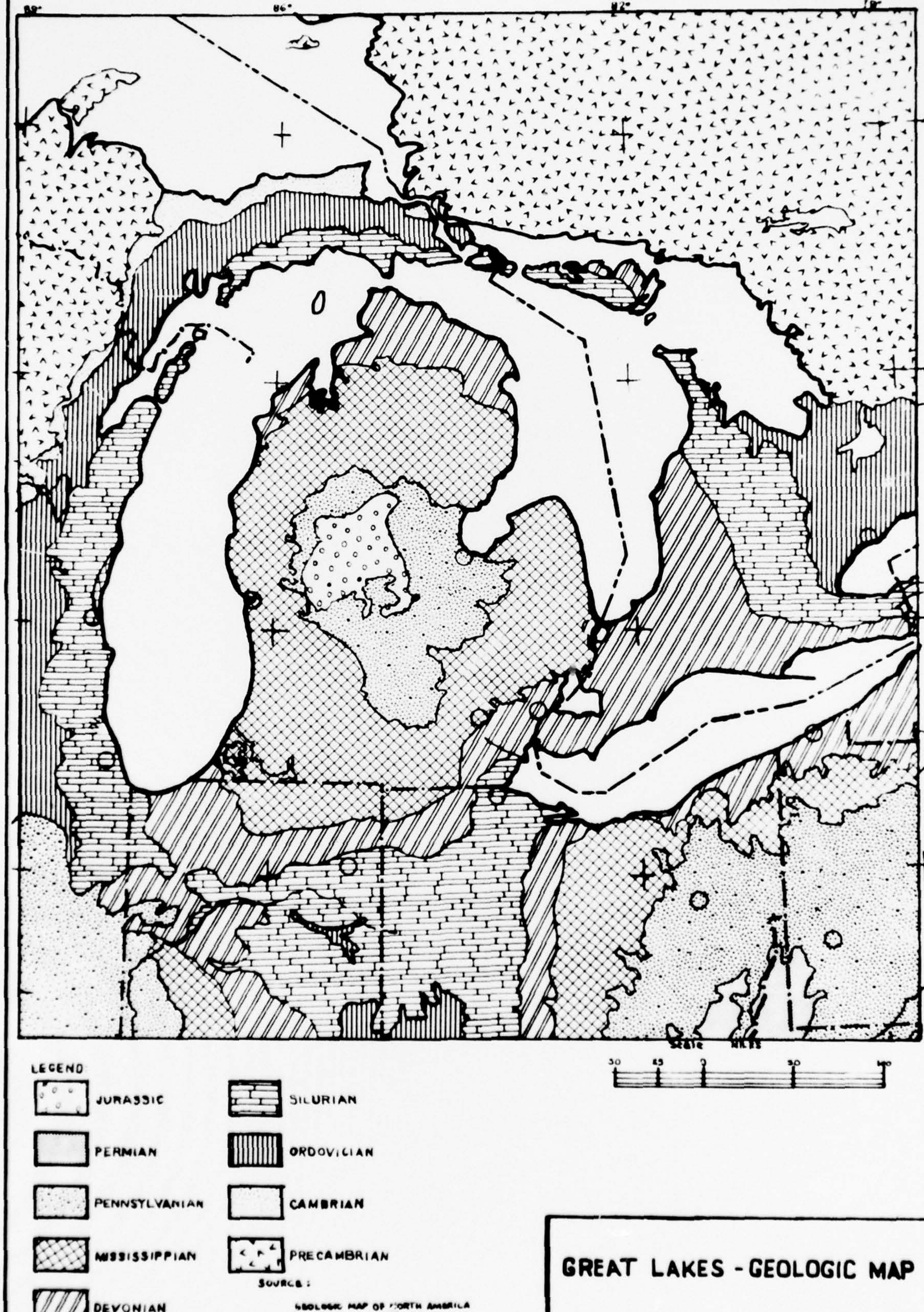
1

ACKNOWLEDGMENT

The Detroit District Corps of Engineers, in the course of the Southeastern Michigan Wastewater Management Study, is publishing these geologic reports by Dr. A. J. Mozola of the Geology Department of Wayne State University. We are indebted to Dr. Mozola for his efforts on our behalf, and for his willingness to provide geological expertise on very short notices.

We also thank the State of Michigan, Department of Conservation Geological Survey for the generous gesture of providing for us Figure 1, Bedrock Geologic Map of Michigan, and for allowing a reprint of Figure 8, Stratigraphic Succession of Rock Units in Michigan.

Finally, we thank the United States Geological Survey for the additional geologic study summarized in Appendices D and E. This study, while not published in its entirety, is available in the Detroit District Office.



GREAT LAKES - GEOLOGIC MAP

TABLE OF CONTENTS

List of Figures

List of Figures (Continued)

ANDREW J. MOZOLA, PH.D.

Consulting Geologist

SUBJECT: SOUTHEASTERN MICHIGAN WASTE-WATER MANAGEMENT PROGRAM - GEOLOGIC CONSIDERATIONS

TO: U. S. Army Engineer District, Detroit
150 Michigan Avenue, P. O. Box 1027, Detroit, Michigan 48231

Attn: Mr. Robert Gregory, Chief Basin Planning Section

DATE: February 23, 1973

BEDROCK GEOLOGY

The project area for subject program is situated along the southeast rim of the Michigan Basin - a structural basin comprised of Paleozoic rock formations which outcrop beneath the soil overburden as concentric bands of varying widths, (Figure 1). Thus, in the project area, the rock formations have a regional trend (strike) that is generally northeast-southwest and an inclination (dip) to the northwest, (Section B-B' - Figure 1). Inclination of the strata is at its maximum in a direction perpendicular to the strike (true dip), and progressively decreases in amount as the direction of inclination approaches the strike of the beds (apparent dip). Regional inclination is generally less than 40 feet per mile except where localized rock structures are present. Where tunnel routes are at some angle to the regional strike, different rock formations will be encountered as tunneling progresses. Tunnel routes parallel to the regional strike would, in theory, remain in the same formation throughout. However, it is not unusual for local rock structures, previously mentioned, to have orientations at right angles, or nearly so, to the regional strike. Local rock structures (folds, faults) do exist within the limits of the project area resulting in local variations in strike and dip, (Figure 2).

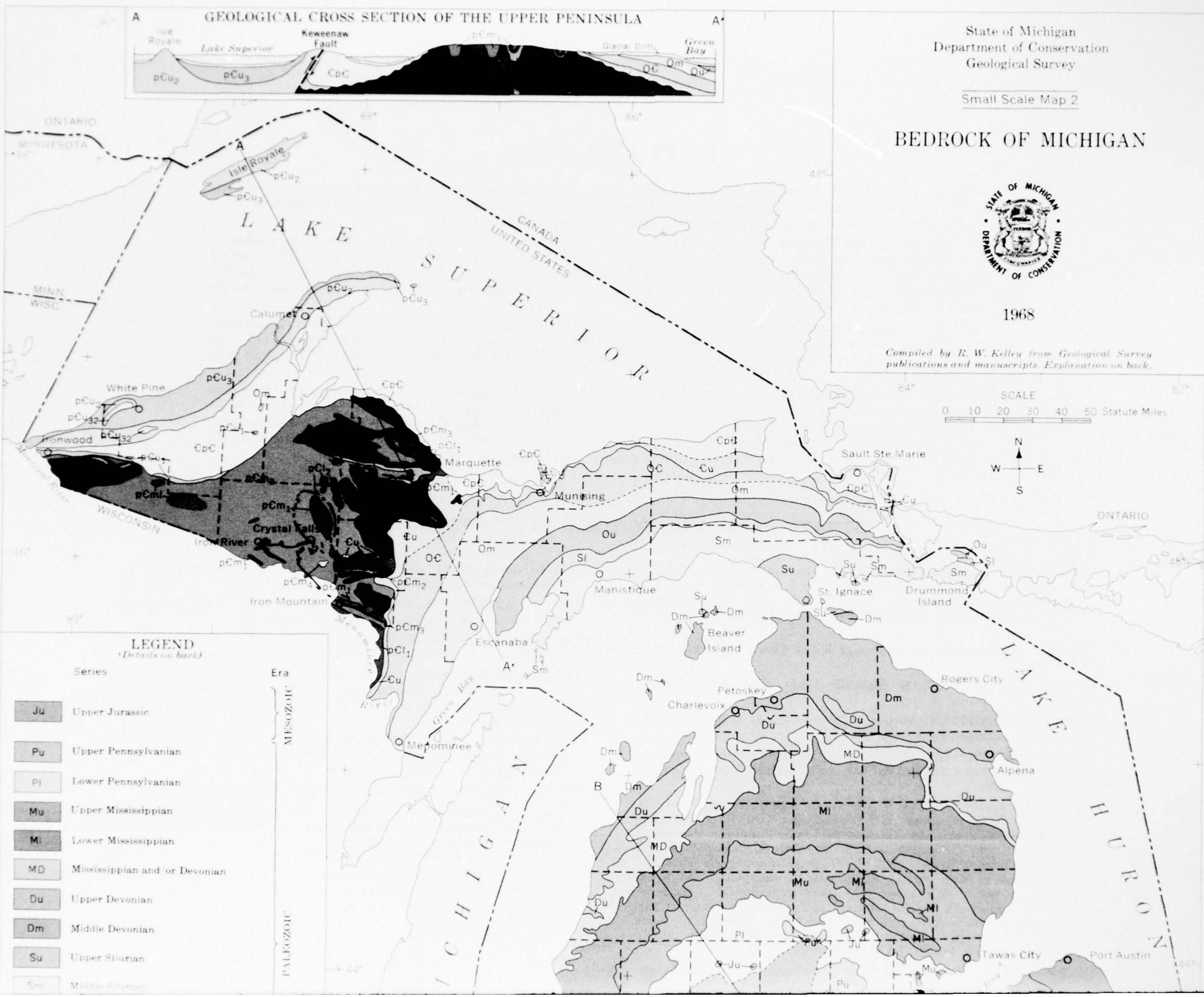
BEDROCK TOPOGRAPHY

With respect to the major physical features of the bedrock surface in Michigan, the proposed tunnel routes are largely within the Erie-Huron rock lowland and to a lesser degree along the southeast slope of the Thumb Upland rock surface (Figure 3). The regional slope of the bedrock surface from the crest of the Thumb Upland (900-1000 feet) is to the southeast with the surface highly dissected by rock valleys some of which are more than 200 feet in depth (Figures 4, 5, 6). Along the floor of some rock valleys, as delineated to date by existing data, may be found enclosed depressions which contribute further to the total amount of bedrock relief (Figure 7). Inasmuch as both the density and distribution of control points (borings and wells reaching or penetrating bedrock) for any given area are rarely ideal, it should not be concluded that occasional scattered low bedrock elevations simply represent enclosed depressions along the valley floor. These same elevations also suggest an alternate possibility that the rock valleys can be considerably deeper than shown. Hence, the bedrock profile along the proposed tunnel should be determined as accurately as possible to minimize "surprises" in the course of tunnel excavation.

BEDROCK STRATIGRAPHY AND GROSS LITHOLOGY

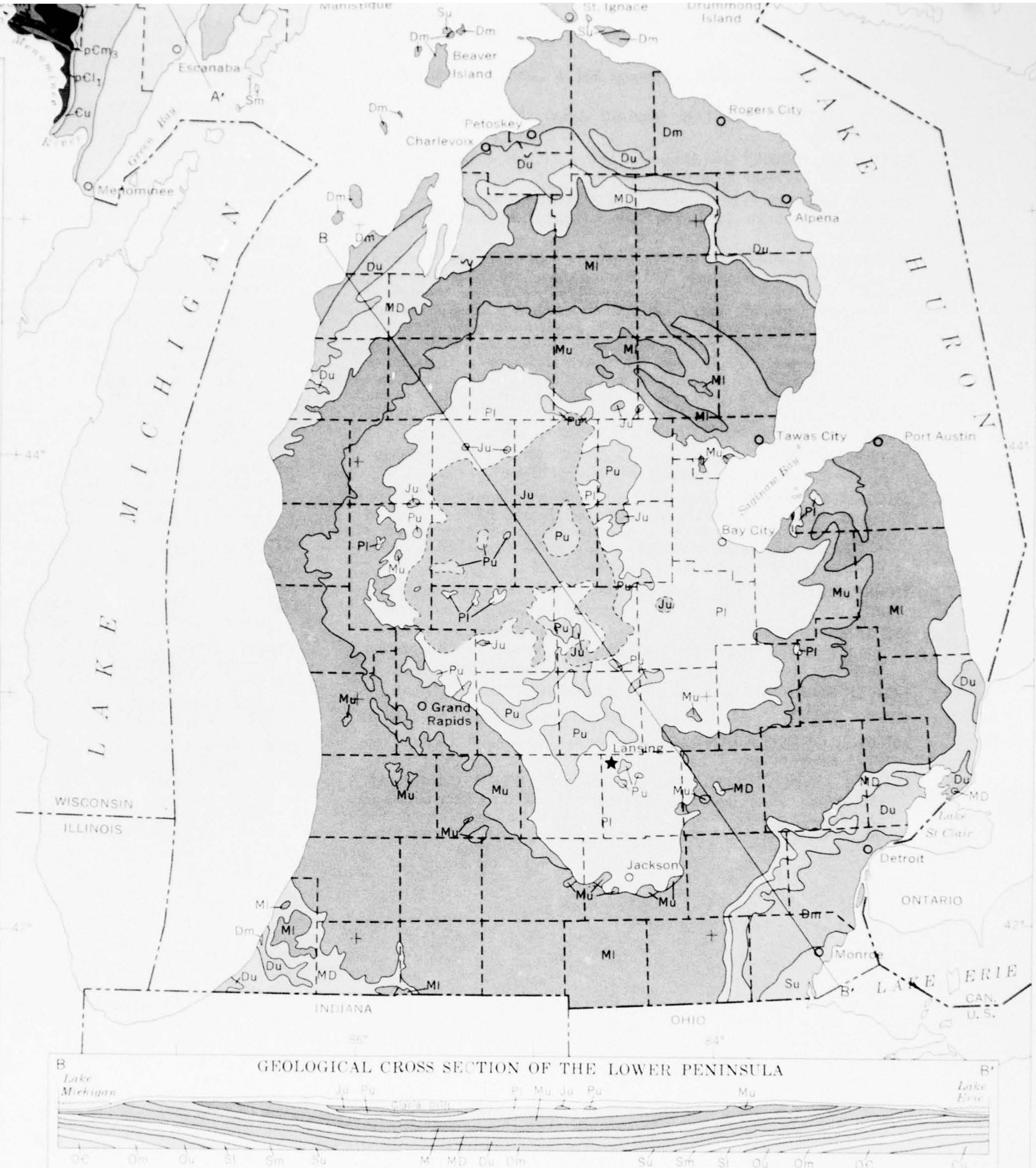
The tunnel routes, as proposed, may involve a stratigraphic sequence that extends from the Salina Group of Late Silurian age (oldest) to the Michigan formation of Late Mississippian age (youngest). The rock units and their dominant lithology are as follows (Figure 8):

Michigan Formation	shale, sandstone, some gypsum, anhydrite
Napolean Formation	sandstone, some shale
Lower Marshall Formation	sandstone, shale
Coldwater Formation	shale, sandstone
Sunbury Formation	shale, dark brown to black
Berea Formation	sandstone, shale
Bedford Formation	shale
Antrim Formation	shale, dark brown to black


State of Michigan
Department of Conservation
Geological Survey
Small Scale Map 2
BEDROCK OF MICHIGAN
STATE OF MICHIGAN • DEPARTMENT OF CONSERVATION
1968
Compiled by R. W. Kelley from Geological Survey publications and manuscripts. Explanation on back.
SCALE
0 10 20 30 40 50 Statute Miles
N
W E
S
GEOLOGICAL CROSS SECTION OF THE UPPER PENINSULA
A
A'
Isle Royale
Lake Superior
Keweenaw Fault
Glacial Drift
Green Bay
LAKE SUPERIOR
LAKE HURON
LAKE MICHIGAN
CANADA
UNITED STATES
ONTARIO
MINNESOTA
MINN.
WISC.
WISCONSIN
Calumet
White Pine
Ironwood
Montreal River
Iron River
Crystal Falls
Iron Mountain
Menominee River
Marquette
Munising
Escanaba
Green Bay
Menominee
Manistique
Sault Ste. Marie
St. Ignace
Drummond Island
Beaver Island
Petoskey
Charlevoix
Rogers City
Alpena
Tawas City
Port Austin
LEGEND
(Details on back)
Series
Era
Ju Upper Jurassic
Pu Upper Pennsylvanian
Pl Lower Pennsylvanian
Mu Upper Mississippian
Ml Lower Mississippian
MD Mississippian and/or Devonian
Du Upper Devonian
Dm Middle Devonian
Su Upper Silurian
Sm Middle Silurian
MESOZOIC
PALEOZOIC

LEGEND
(Details on back)

	Series	Era
Ju	Upper Jurassic	MESOZOIC
Pu	Upper Pennsylvanian	PALEOZOIC
Pl	Lower Pennsylvanian	PALEOZOIC
Mu	Upper Mississippian	PALEOZOIC
Ml	Lower Mississippian	PALEOZOIC
MD	Mississippian and/or Devonian	PALEOZOIC
Du	Upper Devonian	PALEOZOIC
Dm	Middle Devonian	PALEOZOIC
Su	Upper Silurian	PALEOZOIC
Sm	Middle Silurian	PALEOZOIC
Sl	Lower Silurian	PALEOZOIC
Ou	Upper Ordovician	PALEOZOIC
Om	Middle Ordovician	PALEOZOIC
O€	Ordovician and Cambrian	PALEOZOIC
€u	Upper Cambrian	PALEOZOIC
€p€	Cambrian and/or Keweenawan	?
p€u3	Upper Keweenawan	UPPER PRECAMBRIAN
p€u32	Upper and/or Middle Keweenawan	UPPER PRECAMBRIAN
p€u2	Middle Keweenawan	UPPER PRECAMBRIAN
p€u1	Lower Keweenawan	UPPER PRECAMBRIAN
p€m4	*Intrusives*	MIDDLE PRECAMBRIAN
p€m3	Upper Huronian	MIDDLE PRECAMBRIAN
	Iron formation	MIDDLE PRECAMBRIAN
p€m2	Middle Huronian	MIDDLE PRECAMBRIAN
p€m1	Lower Huronian	MIDDLE PRECAMBRIAN
p€mi	*Unassigned intrusives*	?
	Algoman and Laurentian	LOWER PRECAMBRIAN
p€l1	Keewatin	LOWER PRECAMBRIAN



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EXPLANATION

Bedrock is the solid rock at or near the earth's surface. It is generally concealed by an unattached layer of loose fragmented rock. This mantle may have formed in place by decomposition of the underlying parent bedrock: or it may be an accumulation of foreign rock fragments deposited by wind, water, or ice.

Over most of the state, bedrock is buried beneath glacial drift, often several hundred feet deep. In a number of places, however, especially in the western Upper Peninsula and along the Great Lakes shores in the north, bedrock protrudes through the mantle of drift. These outcrops are too few and far between to prepare an adequate bedrock map of the entire state. Such a map can be prepared only by studying the thousands of test borings made in the search for minerals and fuels.

This map shows the area and extent of rock units appearing in the bedrock surface beneath the drift. It is, therefore, an areal geologic map, or more commonly, a geologic map. Michigan's first geologic map appeared about 125 years ago. Many revisions have followed, each contributing new information. The last previous edition was the small scale map published in 1957.

The present edition differs mostly from its predecessor by dividing the Precambrian into more units, the Paleozoic into fewer. Geologic names were taken from Chart I "Stratigraphic Succession in Michigan" published in 1964. Only the more prominent features can be delineated on a map this scale. Most features measuring less than about 1½ to 2 miles across were necessarily excluded, while some of the smallest features tend to be exaggerated. In the cross sections the vertical scale is about 10 to 20 times greater than the surface scale.

STRATIGRAPHIC UNITS USED IN COMPILING MAP

UPPER JURASSIC (*Kimmeridgian Stage*). Consists of former "Permo-Carboniferous red beds". Areal geology after J. E. Sander, unpublished master's thesis, Michigan State University, 1960. Age assignment from A. T. Cross, Michigan State University, 1964 (personal communication).

UPPER PENNSYLVANIAN (*Conemaugh Series*). Consists of Grand River Formation.

LOWER PENNSYLVANIAN (*Pottsville Series*). Consists of Saginaw Formation.

UPPER MISSISSIPPIAN (*Meramecian Series*). Consists of Bayport Limestone and Michigan Formation.

LOWER MISSISSIPPIAN (*Osagian and Kinderhookian Series*). Consists of Marshall Sandstone, Coldwater Shale, and in eastern Lower Peninsula, Sunbury Shale.

MISSISSIPPIAN &/or DEVONIAN. In the eastern Lower Peninsula, consists of Berea Sandstone and Bedford Shale which, on this map, are treated as a unit. In the western Lower Peninsula, consists of Ellsworth Shale, the uppermost unit of which is a sandy carbonate rock correlative of Berea - Bedford. *The boundary between the Mississippian and Devonian systems probably occurs within the lower part of the Bedford and the upper part of the Ellsworth.* The green shale typical of the lower part of the Ellsworth darkens eastward and grades into the upper part of the typical black Antrim in the central Lower Peninsula. Revision of the areal geology of southwest Michigan after G. D. Ells, unpublished manuscript, Michigan Geological Survey, 1967.

UPPER DEVONIAN (*Chautauquan Series*). Consists of Antrim Shale. Thins west, upper part merging with lower Ellsworth.

is the upper part of Lake Superior Sandstone. The boundary between these two units cannot be drawn at this time.

UPPER CAMBRIAN (*St. Croixan Series*). Consists of Munising Formation which is the lower part of Lake Superior Sandstone.

CAMBRIAN &/or KEWEENAWAN. Consists of Jacobsville Sandstone of Middle to Lower Cambrian &/or Upper Keweenawan age.

UPPER KEWEENAWAN. Consists of Freda Sandstone, Nonesuch Shale, and Copper Harbor Conglomerate. The base of the Great Conglomerate, the lowest unit of the Copper Harbor, is the base of Upper Keweenawan series.

UPPER &/or MIDDLE KEWEENAWAN. Consists of: 1) "Porcupine Mountains redrock", an intrusive &/or extrusive rhyolite, 2) "Bergland Hills rhyolite" intrusive.

MIDDLE KEWEENAWAN. Consists of Portage Lake lava series.

LOWER KEWEENAWAN. Consists of South Range series which is primarily basic lava flows with some sandstone. Probably related to the Sibley Series in Ontario. Adapted from H. A. Hubbard, unpublished manuscript, U. S. Geological Survey, 1967.

Intrusives (Middle Precambrian). Minor metamorphosed gabbro and granite bodies too limited to show on this scale except the Peavy Pond Complex in southeast Iron County.

UPPER HURONIAN. Consists of Paint River and Baraga groups, and Michigamme, Tyler, and Clarksburg formations. *The term Huronian is equivalent to term Animikie now adopted by the U. S. Geological Survey.*

Iron formation. Consists of: 1) Riverton Iron-formation (Paint River Group),

Carboniferous red beds". Areal geology after J. E. Sander, unpublished master's thesis, Michigan State University, 1960. Age assignment from A. T. Cross, Michigan State University, 1964 (personal communication).

UPPER PENNSYLVANIAN (*Conemaugh Series*). Consists of Grand River Formation.

LOWER PENNSYLVANIAN (*Pottsville Series*). Consists of Saginaw Formation.

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UPPER DEVONIAN (*Chautauquan Series*). Consists of Antrim Shale. Thins west, upper part merging with lower Ellsworth.

MIDDLE DEVONIAN (*Erian and Ulsterian Series*). Consists of Traverse Group, Rogers City and Dundee limestones, Detroit River Group, and Bois Blanc Formation. *Neither the Mackinac Breccia, which contains rock of both Middle Devonian and Upper Silurian age, nor the Garden Island Formation of Lower Devonian age, can be shown on this scale.*

UPPER SILURIAN (*Cayugan Series*). Consists of Bass Islands and Salina groups.

MIDDLE SILURIAN (*Niagaran Series*). Consists of Engadine Dolomite and Manistique and Burnt Bluff groups. The base of Lime Island Dolomite, the lowest unit of the Burnt Bluff, is basal Niagaran.

LOWER SILURIAN (*Alexandrian Series*). Consists of Cataract Group.

UPPER ORDOVICIAN (*Cincinnatian Series*). Consists of Richmond Group.

MIDDLE ORDOVICIAN (*Mohawkian Series*). Consists of Trenton and Black River groups.

LOWER ORDOVICIAN (*Canadian Series*) & UPPER CAMBRIAN (*St. Croixan Series*)—*undivided*. Consists of Prairie du Chien Group of Ordovician age and Trempealeau Formation of Cambrian age. Prairie du Chien is essentially the former Hermansville, while Trempealeau these two units cannot be drawn at this time.

UPPER CAMBRIAN (*St. Croixan Series*). Consists of Munising Formation which is the lower part of Lake Superior Sandstone.

CAMBRIAN & /or KEWEENAWAN. Consists of Jacobsville Sandstone of Middle to Lower Cambrian & /or Upper Keweenawan age.

UPPER KEWEENAWAN. Consists of Freda Sandstone, Nonesuch Shale, and Copper Harbor Conglomerate. The base of the Great Conglomerate, the lowest unit of the Copper Harbor, is the base of Upper Keweenawan series.

UPPER & /or MIDDLE KEWEENAWAN. Consists of: 1) "Porcupine Mountains redrock", an intrusive & /or extrusive rhyolite, 2) "Bergland Hills rhyolite" intrusive.

MIDDLE KEWEENAWAN. Consists of Portage Lake lava series.

LOWER KEWEENAWAN. Consists of South Range series which is primarily basic lava flows with some sandstone. Probably related to the Sibley Series in Ontario. Adapted from H. A. Hubbard, unpublished manuscript, U. S. Geological Survey, 1967.

Intrusives (Middle Precambrian). Minor metamorphosed gabbro and granite bodies too limited to show on this scale except the Peavy Pond Complex in southeast Iron County.

UPPER HURONIAN. Consists of Paint River and Baraga groups, and Michigamme, Tyler, and Clarksburg formations. *The term Huronian is equivalent to term Animikie now adopted by the U. S. Geological Survey.*

Iron formation. Consists of: 1) Riverton Iron-formation (Paint River Group), Amasa Iron-formation (Baraga Group), and Bijiki Iron-formation of Upper Huronian age, and 2) Negaunee, Vulcan (Menominee Group), and Ironwood iron-formations of Middle Huronian age.

MIDDLE HURONIAN. Consists of: 1) Menominee Group, 2) Negaunee and Ironwood iron-formations, and 3) Siamo, Ajibik and Palms formations.

LOWER HURONIAN. Consists of Chocolay Group, and Wewe, Kona, *Mesnard, and Sunday formations.*

Unassigned intrusives (Middle & /or Lower Precambrian). Granites which may be Lower Precambrian or equivalent to the post-Huronian intrusives shown previously as Killarney Granite.

ALGOMAN & LAURENTIAN—*undivided* (Lower Precambrian). Consists of granite and granite gneiss.

KEEWATIN. Consists of: 1) Granite gneiss and metamorphosed volcanics and sediments of the Dickinson Group, and 2) Metamorphosed volcanics and sediments elsewhere. Includes "greenstone" of the Marquette and Gogebic areas, and the Precambrian rock along the west boundary of Menominee County shown previously as Killarney Granite, R. C. Reed, Michigan Geological Survey, 1967 (personal communication).

Figure 1: Bedrock Geologic Map of Michigan.

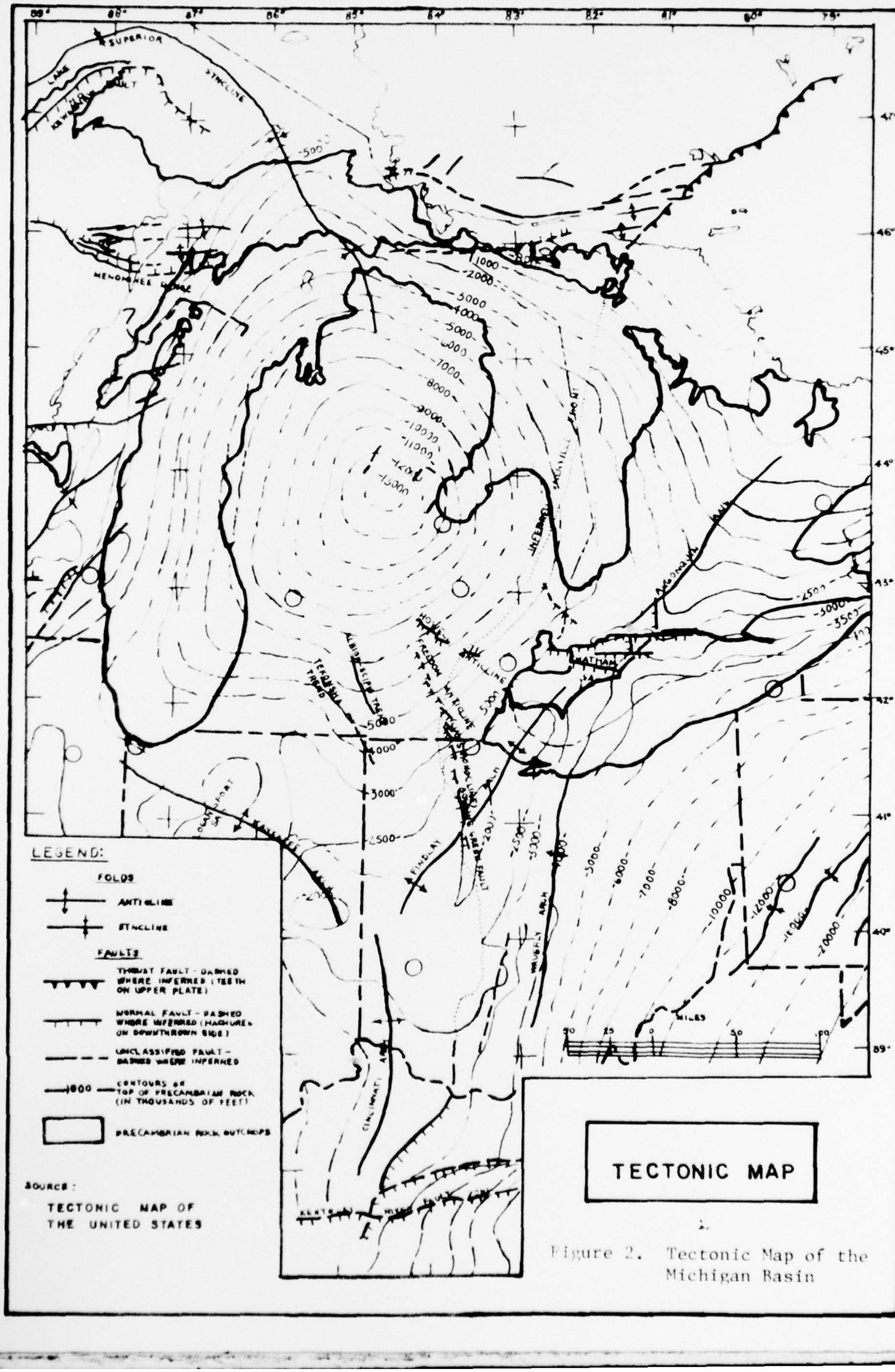


Figure 2. Tectonic Map of the Michigan Basin

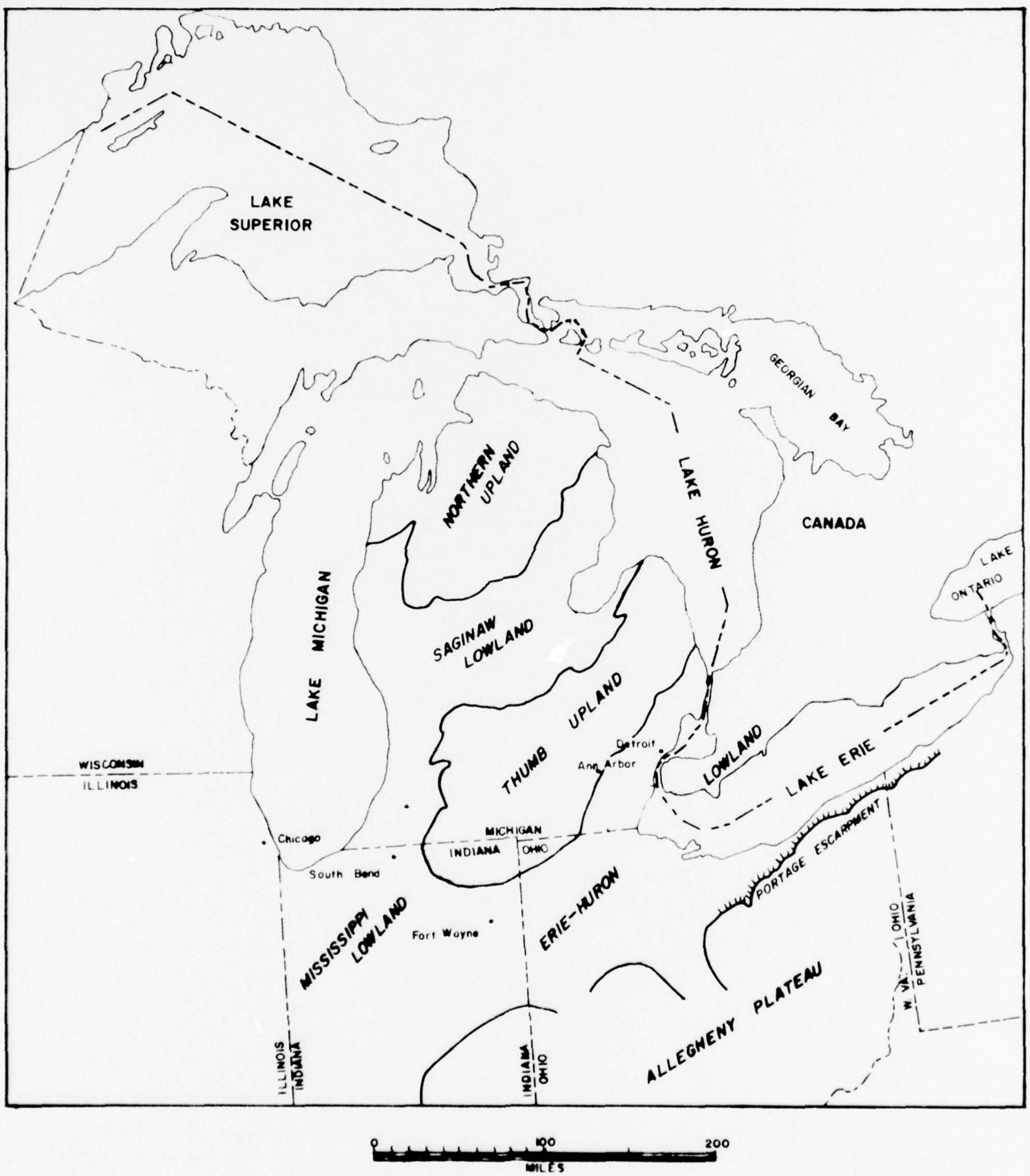


Figure 3: Physiographic Features of the Bedrock Surface of Michigan and Adjacent Areas.

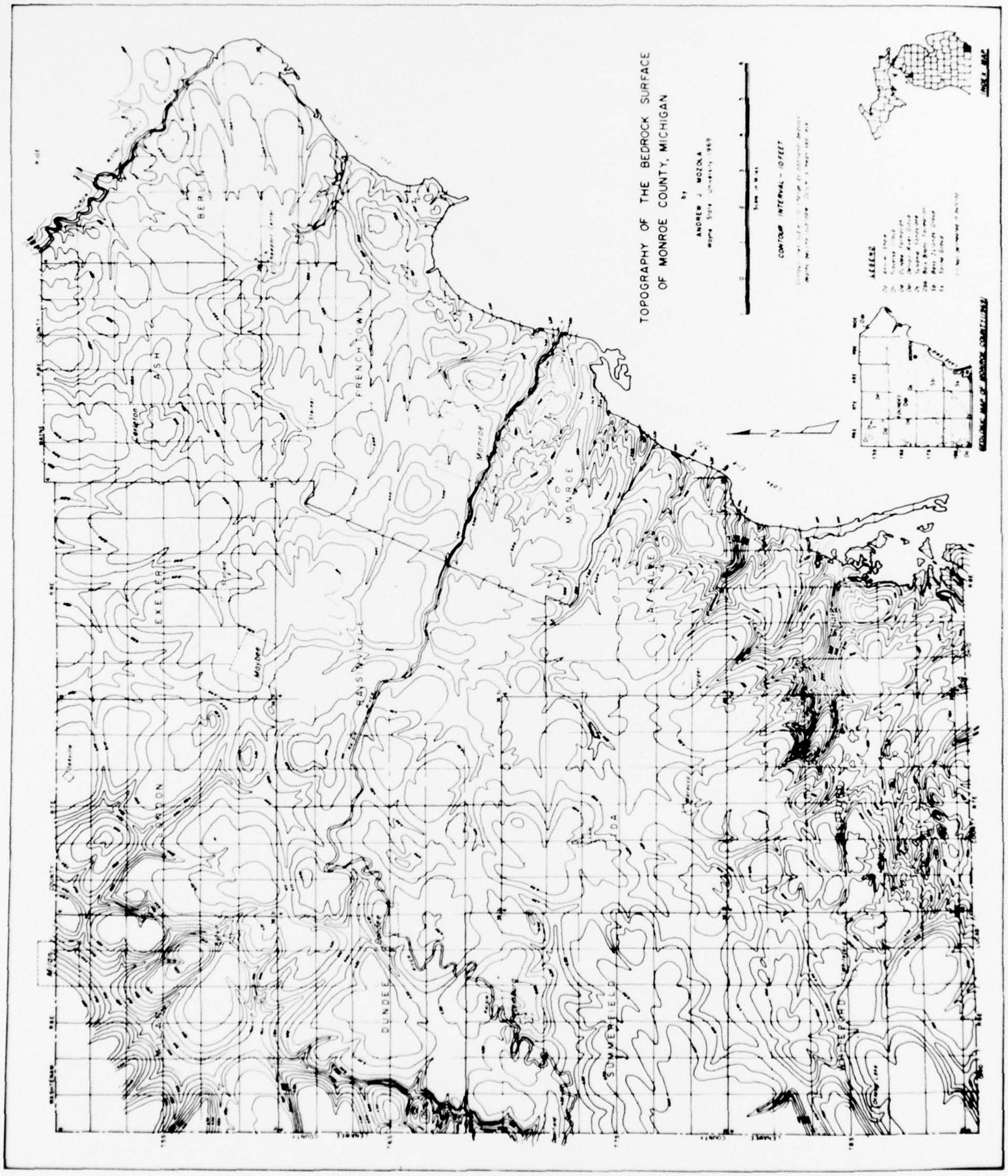


Figure 4: Topography of the Bedrock Surface of Monroe County, Michigan.

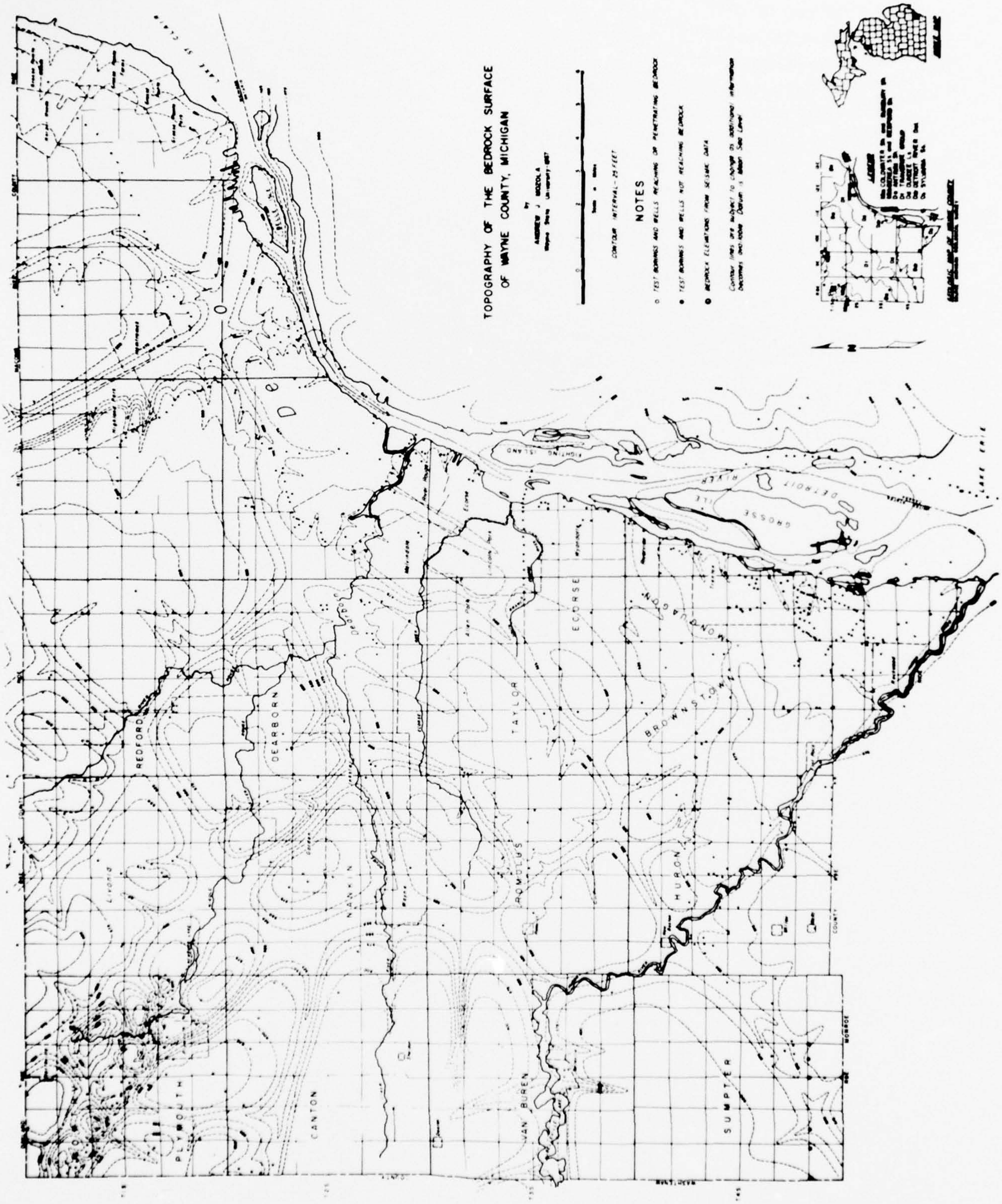


Figure 5: Topography of the Bedrock Surface of Wayne County, Michigan.

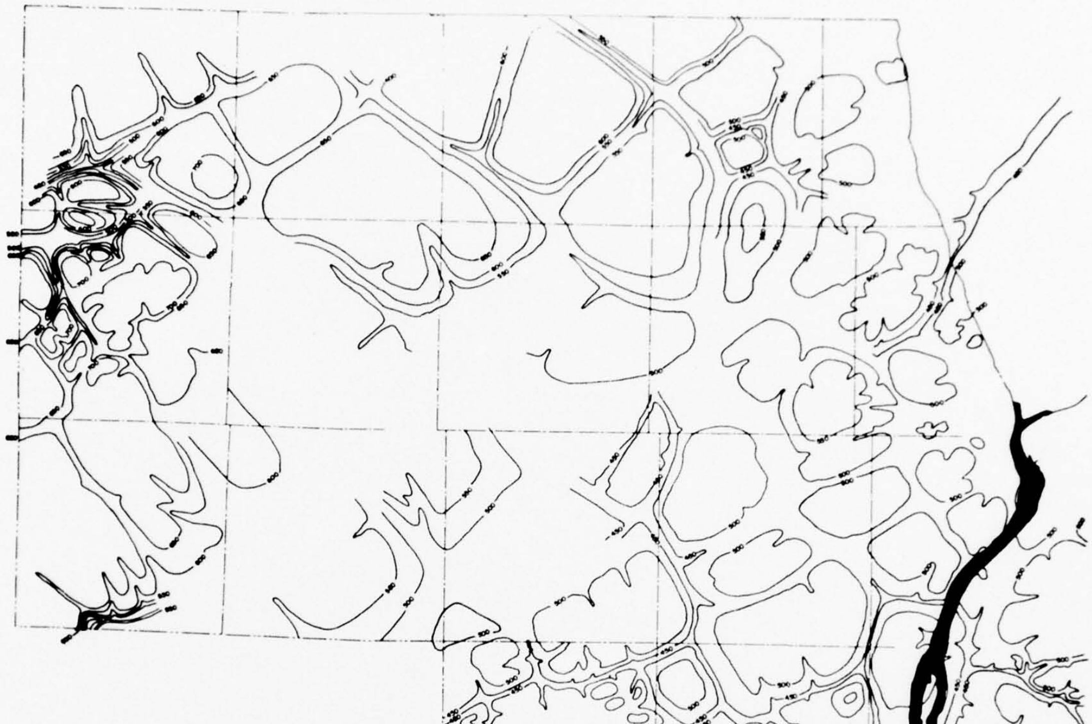


Figure 6: Topography of the Bedrock Surface of St. Clair County, Michigan.

Contour Interval 50 feet.

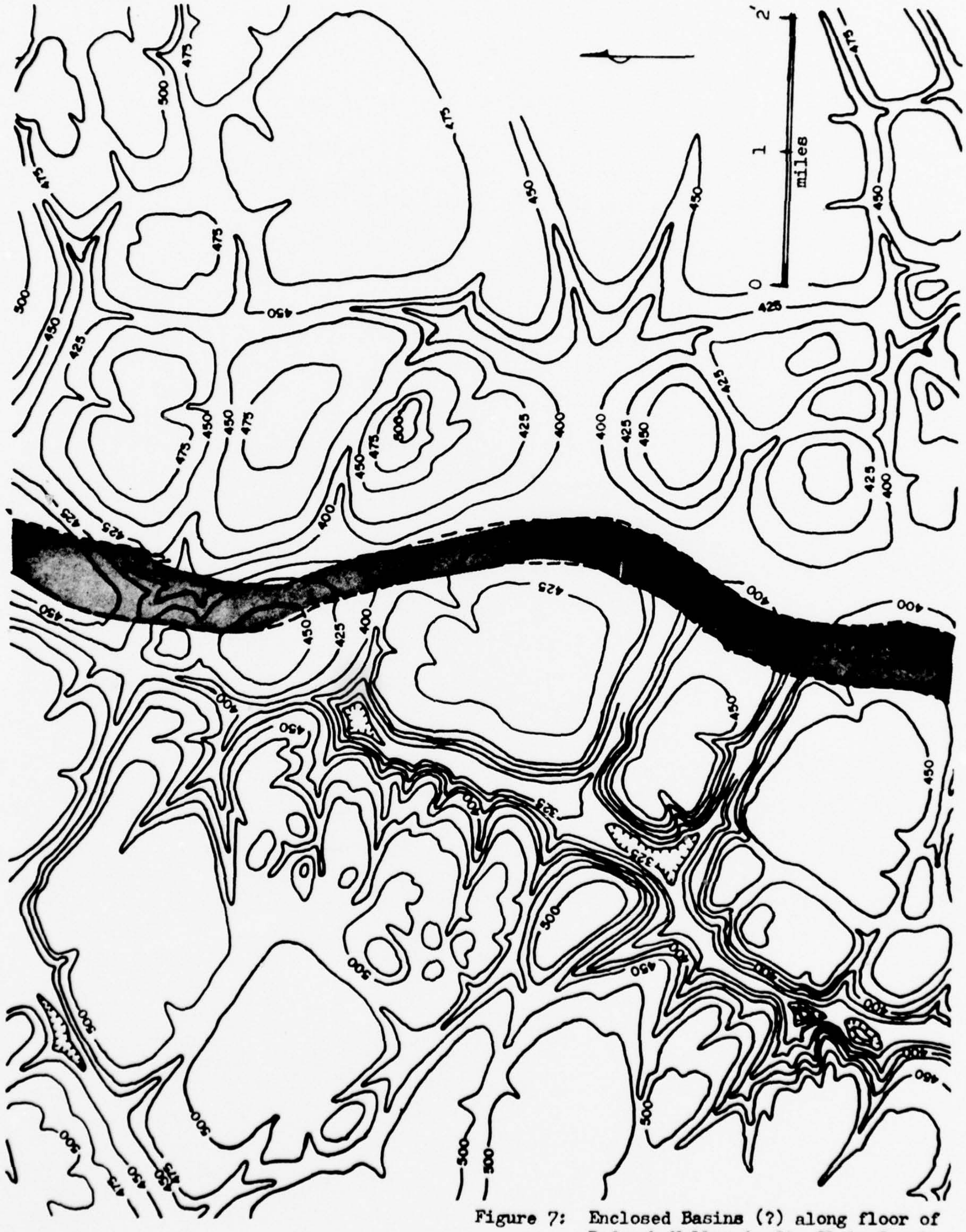


Figure 7: Enclosed Basins (?) along floor of Bedrock Valley in St. Clair County, Michigan.

Contour Interval 25 feet.

Figure 7A: Enclosed Basins (?) along floor of Bedrock Valley in St. Clair County, Michigan.

Contour Interval 25 feet.

STRATIGRAPHIC SUCCESSION IN MICHIGAN

PALEOZOIC THROUGH RECENT

PLEISTOCENE NOMENCLATURE

ERA	SYSTEM	SERIES	STAGE	
CENOZOIC	QUATERNARY	RECENT		
		PLEISTOCENE	Wisconsin Glaciation	Valders Stade
				Two Creeks Interstade
				Mankato Stade (Pt. Huron?)
				Cary Stade
				Tazewell Stade
			Sangamon Interglaciation	
			Illinoian Glaciation	

OUTCROP NOMENCLATURE

GEOLOGIC TIME: ERA	PERIOD	EPOCH	TIME-STRATIGRAPHIC: SYSTEM	SERIES	ROCK-STRATIGRAPHIC: GROUP	FORMATION	MEMBER
MESOZOIC	JURASSIC	LATE	JURASSIC	KIMERIDGIAN			
	PENNSYLVANIAN	LATE	PENNSYLVANIAN	CONEMAUGH		Grand River Fm	Ionia, Eaton, and Woodville Sandstones
		EARLY		POTTSVILLE		Saginaw Fm	Verne Ls
	MISSISSIPPIAN	LATE	MISSISSIPPIAN	MERAMECIAN	GRAND RAPIDS	Bayport Ls	
						Michigan Fm	
		EARLY		OSAGIAN		Marshall Ss	Napoleon Ss
				KINDERHOOKIAN		Coldwater Sh	
	MISSISSIPPIAN-DEVONIAN				Unassigned	Ellsworth Sh (Western Michigan)	
	DEVONIAN	LATE	DEVONIAN	CHAUTAUQUAN		Antrim Sh	
				SENECAN	TRAVERSE	Squaw Bay Ls	
		MIDDLE		ERIAN		Thunder Bay Ls	
						Potter Farm Fm	
						Norway Point Fm	
						Four Mile Dam Fm	
						Alpena Ls	
						Newton Creek Ls	
						Genshaw Fm	Killians
						Ferron Point Fm	
						Rockport Quarry Ls	
						Bell Sh	
						Rogers City Ls	
						Dundee Ls	
				ULSTERIAN	DETROIT RIVER	Anderdon Fm	
						Lucas Fm	
						Amherstburg Fm	
						Sylvania Ss	
					MACKINAC BRECCIA	Bois Blanc Fm	
		EARLY				Garden Island Fm	

DOMINANT LITHOLOGY

SUBSURFACE NOMENCLATURE

ROCK-STRATIGRAPHIC

FORMATION	MEMBER	GROUP	Approximate maximum thickness, in feet, of rock units in the subsurface NO SCALE
"Red Beds" (unnamed)			220
Grand River Fm			750
Saginaw Fm			
Bayport Ls		GRAND RAPIDS	160
Michigan Fm			600
Marshall Ss	Napoleon Ss		330
Coldwater Sh			1300
Sunbury Sh	(Eastern Michigan)		160
Berea Ss			260
Bedford Sh			240
Antrim Sh			660
Squaw Bay Ls		TRAVERSE Generally undivided in subsurface	830
Rogers City Ls			
Dundee Ls			475
Lucas Fm		DETROIT RIVER	1450
Amherstburg Fm			
Sylvania Ss			
Bois Blanc Fm			800
Garden Island Fm			100

MICHIGAN DEPARTMENT OF CONSERVATION

Ralph A. MacMullan, Director

GEOLOGICAL SURVEY

Gerald E. Eddy, State Geologist

ACKNOWLEDGEMENT: Compiled with the counsel of colleagues in this department, the U. S. Geological Survey, Michigan's universities, other state Geological Surveys, and geologists within Michigan's oil and gas industry. Dr. Aureal T. Cross, Department of Geology, Michigan State University, identified rocks of Mesozoic age and suggested provisional age assignments.

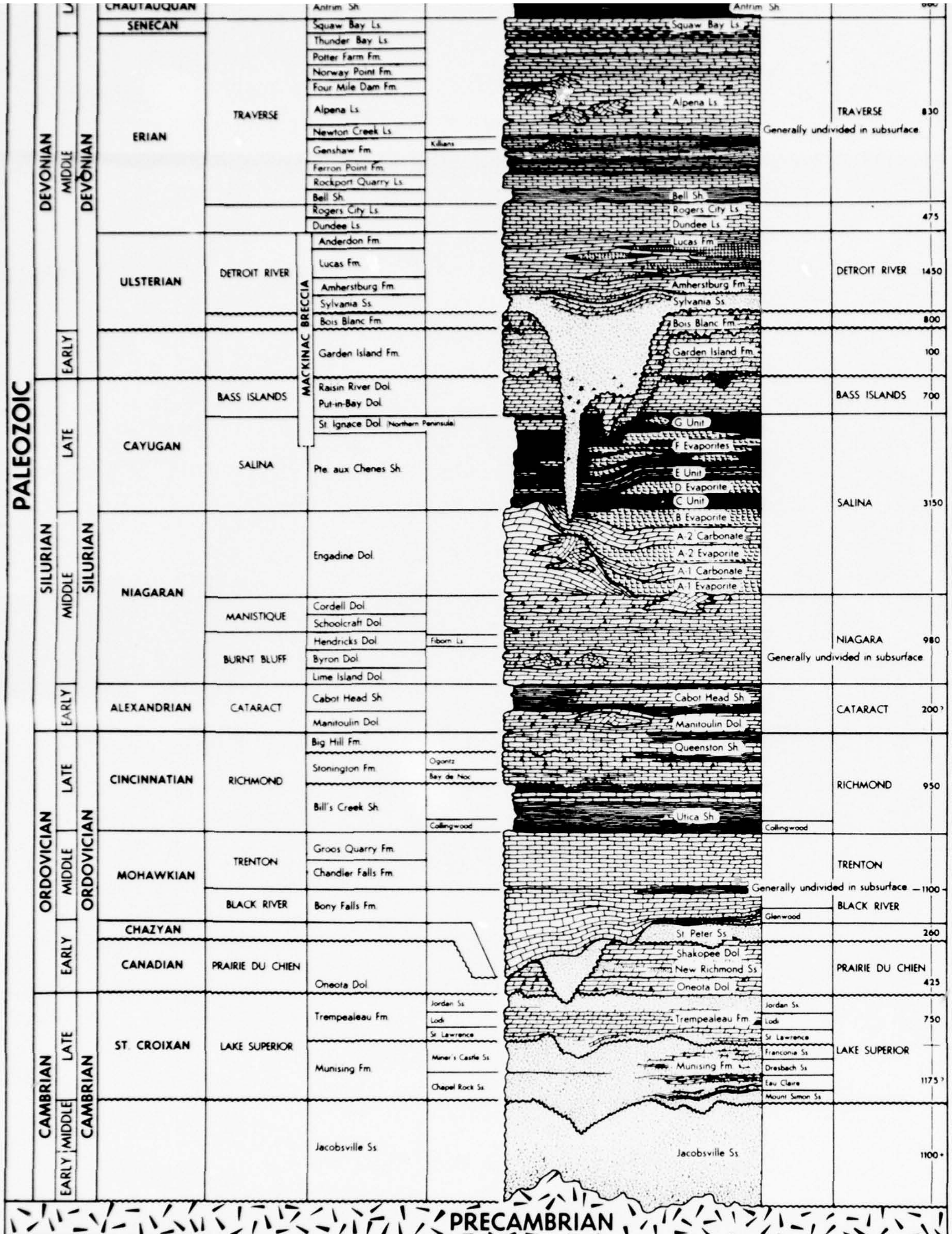
GEOLOGIC NAMES COMMITTEE

Garland D. Ells, Chairman, Robert W. Kelley, Secretary, Harry J. Hardenberg, L. David Johnson, Harry O. Sorensen

INFORMAL TERMS

Principal oil and gas pays, and informal terms used in petroleum exploration and applied to parts of formations or groups in the subsurface

STRATIGRAPHIC POSITION	INFORMAL TERMS	PAYS
Basal sandstones of Saginaw Fm	Parma sandstone	
In lower part of Michigan	triple gyp	
	brown lime	
	stray-stray ss	Gas
	stray dol	
	stray ss	Gas & Oil
Marshall Ss		Gas & Oil
Coldwater Sh	Coldwater lime	
	Weir sand	Gas
	Coldwater red-rock	
In upper part of Ellsworth Sh	"Berea" (Western Michigan)	Oil & Gas
Berea Ss	Berea sand (Eastern Michigan)	Oil & Gas
Squaw Bay Ls	Squaw Bay	Oil & Gas
Upper part of Traverse Group in Western Michigan	Traverse formation	
	Traverse lime	Oil & Gas
	Stoney Lake zone	Oil & Gas
Rogers City Ls		Oil & Gas
Dundee Ls		Oil & Gas
Dundee Ls (?), Upper part of Lucas Fm (?)	Reed City zone	Oil & Gas
In Lucas Fm	massive salt	
	big salt	
	sour zone	Oil & Gas
	massive anhydrite	
	big anhydrite	
	Richfield zone	Oil & Gas
Amherstburg Fm	black lime	
Part of Salina Group E Unit	E zone (or Kintigh zone)	Oil
Divisions of A-2 Carbonate in Western Michigan	A-2 dolomite	Gas
	A-2 lime	
A-1 Carbonate	A-1 dolomite	Oil & Gas
Upper part of Niagaran Series	brown Niagaran	Oil & Gas
	gray Niagaran	
	white Niagaran	
Part of Niagaran Series	Clinton shale (Eastern Michigan)	
Trenton Group		Oil & Gas



part of Lucas Fm (?) ——— Reed City zone ——— Oil & Gas

In Lucas Fm ——— massive salt / big salt / sour zone ——— Oil & Gas; massive anhydrite / big anhydrite / Richfield zone ——— Oil & Gas

Amherstburg Fm ——— black lime

Part of Salina Group E Unit ——— E zone (or Kintigh zone) ——— Oil

Divisions of A-2 Carbonate in Western Michigan ——— A-2 dolomite / A-2 lime ——— Gas

A-1 Carbonate ——— A-1 dolomite ——— Oil & Gas

Upper part of Niagaran Series ——— brown Niagaran / gray Niagaran / white Niagaran ——— Oil & Gas

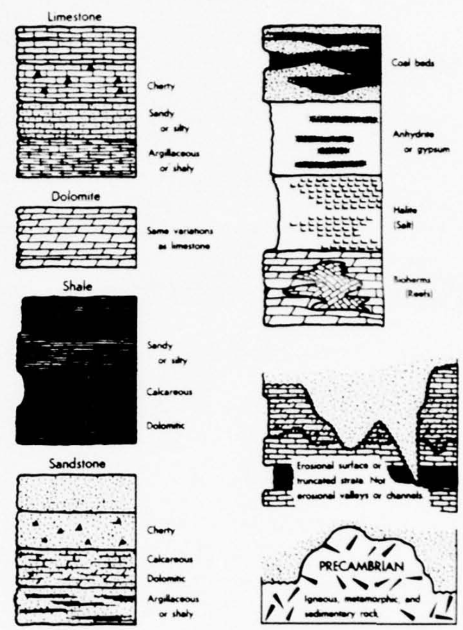
Part of Niagaran Series ——— Clinton shale (Eastern Michigan)

Trenton Group ——— Oil & Gas

Black River Group ——— Black River formation / Black River shale / Van Wert zone ——— Oil & Gas

Oneota Dol ——— Oil

EXPLANATION



GEOLOGIC NAMES COMPILATIONS: Harry O. Sorensen, Cambrian and Ordovician; Robert W. Kelley, Early and Middle Silurian; Garland D. Ells, Late Silurian through Detroit River Group of Devonian age; Harry J. Hardenberg, Dundee Limestone through Traverse Group of Devonian age; L. David Johnson, Antrim Shale through the Pennsylvanian System; F. Wells Terwilliger, glacial geology of the Cenozoic.

CHART 1
1964

Traverse Group	limestones, dolomites, and shales
Dundee Formation	limestone, some dolomite
Detroit River Group	
Anderdon Formation	limestone, some dolomite
Amherstberg Formation	dolomite
Lucas Formation	dolomite
Sylvania Formation	sandstone, some sandy dolomite
Bois Blanc Formation	dolomite
Bass Islands Group	
Raisin River Formation	dolomite
Put-in-Bay Formation	dolomite
Salina Group (upper)	dolomite, shaly dolomite, shale

Below the Traverse Group, the stratigraphic sequence consists essentially of carbonate rocks except for the Sylvania sandstone and occasional shale horizons. The carbonate rocks consist of limestones and dolomites along with their shaly and sandy counterparts. Predominant minerals for the carbonate rocks are calcite and dolomite which have a hardness of three on Moh's Scale of 10. The Sylvania is unique since it consists predominantly of subrounded to rounded quartz sand grains (98%+). Though quartz (hardness 7) is highly abrasive the sand grains are poorly cemented.

The Traverse Group is represented by limestones, dolomites, and shales which still remain undivided in terms of formational units in the subsurface of southeastern Michigan. Ratio of carbonate rock to shale in the total Traverse section can vary from place to place. Logs of wells in one area may show a dominance of limestones and dolomites; elsewhere shales, limestone, and dolomite will constitute the sequence, and in other locales a dominance of shale prevails. The upper boundary, or top, of the Traverse Group is easily differentiated from the overlying dark brown to black Antrim shale formation. The base of the Traverse Group may be difficult to recognize in those areas where limestones of this group rest directly on limestone beds of the Dundee formation.

Above the Traverse Group a clastic sequence prevails, principally shales,

sandstones with occasional carbonate rock horizons and minor occurrences of gypsum and anhydrite. Shales are largely composed of clay minerals (illite most common) which have a hardness of 2 to 2.5 on Moh's scale. Quartz is the prevailing mineral in sandstones and hence abrasive. Many of the sandstones are fine-grained, micaceous, and well cemented. Thin sandstone beds alternating with shale may be encountered in the Coldwater formation. General descriptions of the rock units are contained in a letter report, dated July 29, 1972, and submitted to the Basin Planning Section.

Detailed descriptions of the rock units may be obtained from existing oil and gas logs situated along or adjacent to the proposed tunnel routes. These logs have been collated by township and sections, summarized with respect to rock units, depths, thicknesses, elevation of rock unit tops and submitted to the Basin Planning Section. From these records, it can be noted that in general the rock units increase in thickness to the northwest - in the direction of dip towards the center of the structural basin. Variations in thickness of various rock units may be attributed to (a) local thickening of unit, (b) the effect of local rock structure, or (c) the inherent difficulty in the recognition of formation tops (upper boundaries or contacts) in the subsurface. Dip of the strata along the proposed routes will change depending upon the influence of local rock structures and the direction of the routes in relation to the strike of the sedimentary rocks. As previously mentioned the dip of the beds is rather gentle and not steeply inclined as shown on the previously submitted structure cross sections which were compiled with a vertical exaggeration of 50 times the horizontal scale.

SOIL OVERBURDEN

The soil overburden consists of unconsolidated debris that was left behind by past glaciers. Its thickness within the project area varies from a

few inches to 400 feet or more. Generally, the thickest occurrences of drift may be expected where end-moraine features (Figure 9) cross or coincide with the buried bedrock valleys. Though drift includes a wide spectrum of grain sizes, from clays on up to boulders of large dimensions, and characterized by both gradual and abrupt changes areally and in depth, it is generally subdivided into two broad categories, namely till and glacio-fluvial or outwash deposits (Figure 10). Till represents deposition directly by ice and, hence, is a heterogeneous admixture both in terms of rock and mineral composition and in grain sizes - from clay to boulders. In essence, it is a clay rich admixture that is highly variable in its physical characteristics from place to place. It is difficult to assess the true character of till from soil borings because the frequency and distribution of cobbles and boulders throughout is rarely, if ever, uniform. Their presence in till deposits may range from a sparse distribution to such concentrations as to justify such descriptions as "boulder clay" and "boulder pavements". Landscape features in which till is dominantly present include the end-moraines (some of which have been deposited in water) and till plains (also known as ground moraine).

In contrast to till, glacio-fluvial, or outwash, materials represent glacial meltwater deposits and as such are sorted, stratified and frequently cross-bedded. They are sands and/or gravels in which the finer fractions, silt and clay, are of subordinate occurrence. Glacio-fluvial materials are associated with such features as outwash plains, marginal outwash channels, glacial spillways, kames, and eskers.

Since Michigan has experienced repeated episodes of glaciation and deglaciation, each glacial episode further complicated by minor advances and retreats of its ice-margin, it is logical to conclude that the total drift represents a body of diverse lithologic characteristics. Glacio-fluvial

materials can be contained within till features such as end and ground moraines; conversely, till may be present within glacio-fluvial deposits.

GROUND WATER OCCURRENCE

The crest of the Thumb Upland divide is the principal topographic divide in southeastern Michigan and separates surface drainage to the north from that to the southeast into the Great Lakes System. Along this divide surface elevations may range as high as 1200 feet above sea level with a maximum relief of 600 feet if the level of Lake Erie (571 feet) is taken as the local datum. The bedrock divide also approximates the topographic divide, and along this crest a number of elevations between 900 and 1000 feet are known to exist. In the project area, the highest and lowest bedrock elevations known to this investigator are 967 feet (northern Oakland County) and 243 feet (northwest of Anchor Bay in Macomb County) respectively. This is a difference of 724 feet and suggests that the bedrock relief equals, if not exceeds, the present topographic relief. Yet there is no assurance that the highest and lowest rock elevations are represented among the existing oil, gas, water records and soil borings as of this date. As a consequence of repeated glacial episodes there is good evidence that the bedrock divide has been breached by through valleys. Finally, the water-table divide approximates the topographic and bedrock divides so that the regional movement of ground water in the project area is to the southeast and with a head difference of several hundred feet between the highest and lowest points of the water-table surface.

<u>DRIFT</u>: The occurrence of ground water in the drift overburden is under both water-table (unconfined) and artesian (confined) conditions (Figure 12). Surface deposits of sand and/or gravel constitute the water-table, or unconfined aquifers provided they are of sufficient magnitude both areally and

Figure 9: End-Moraines of Michigan.

Figure 10: Glacial Features of Southern Michigan, Northern Indiana, and Northern Ohio (after Geological Society of America).

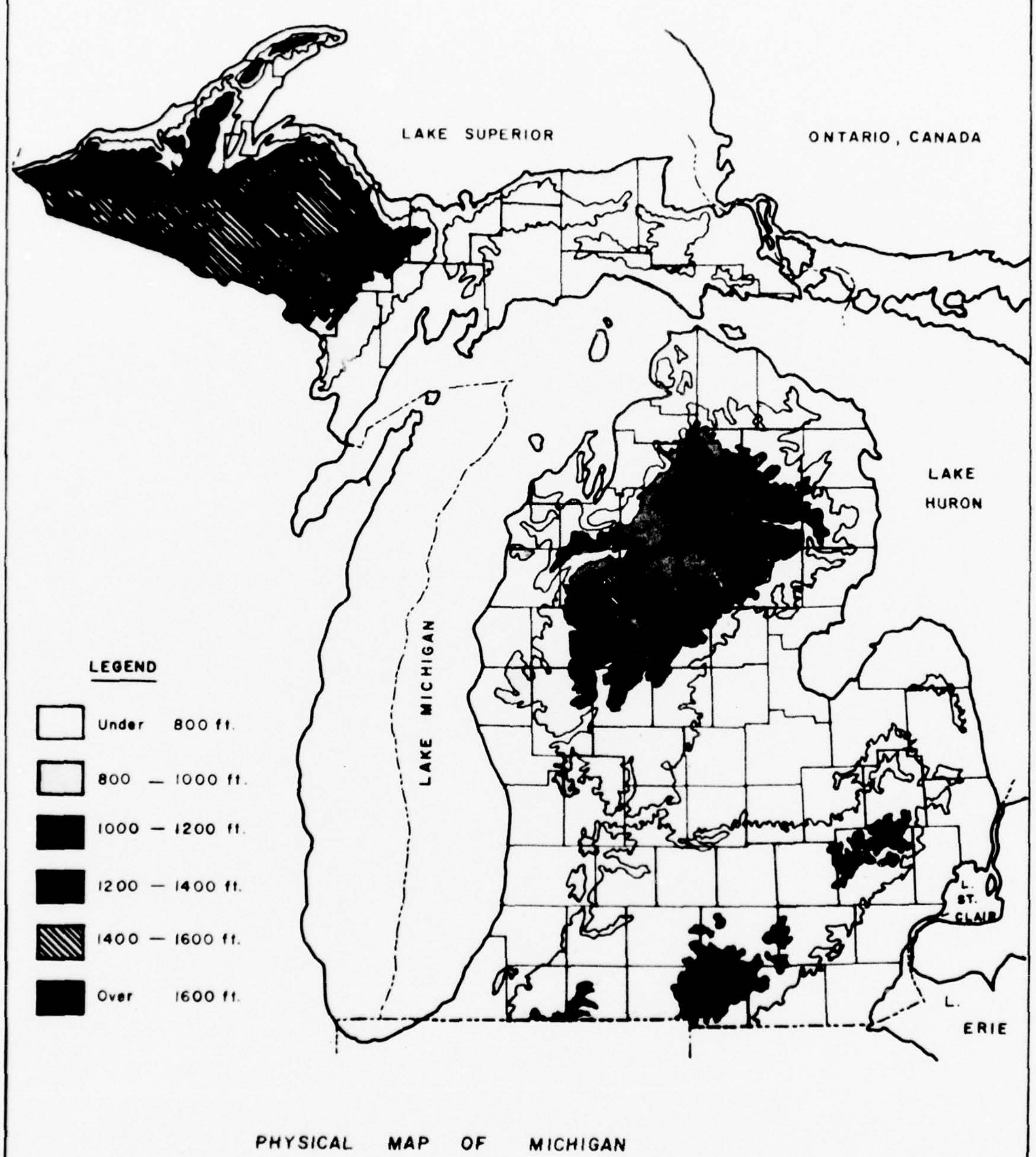


Figure 11: Physical Map of Michigan.

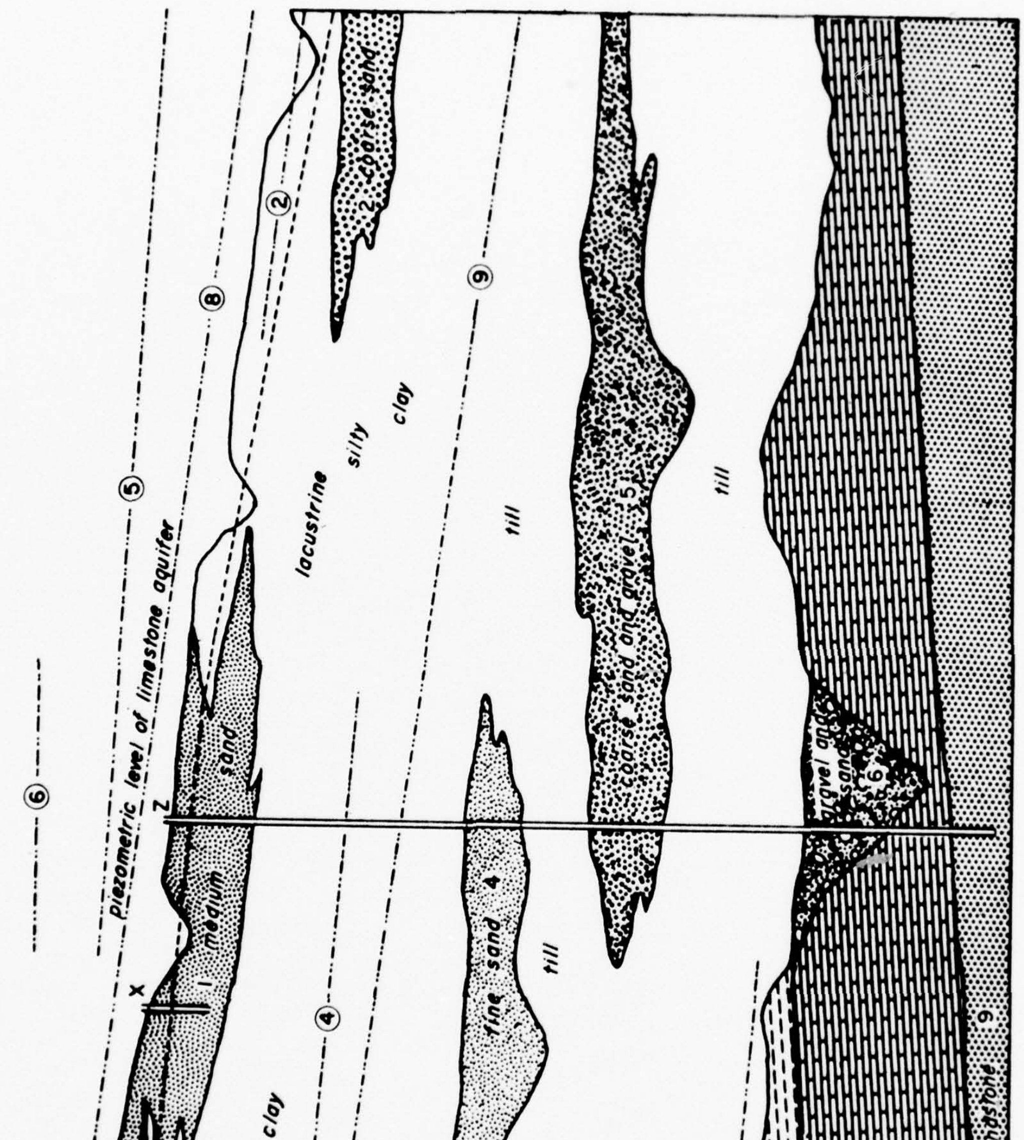


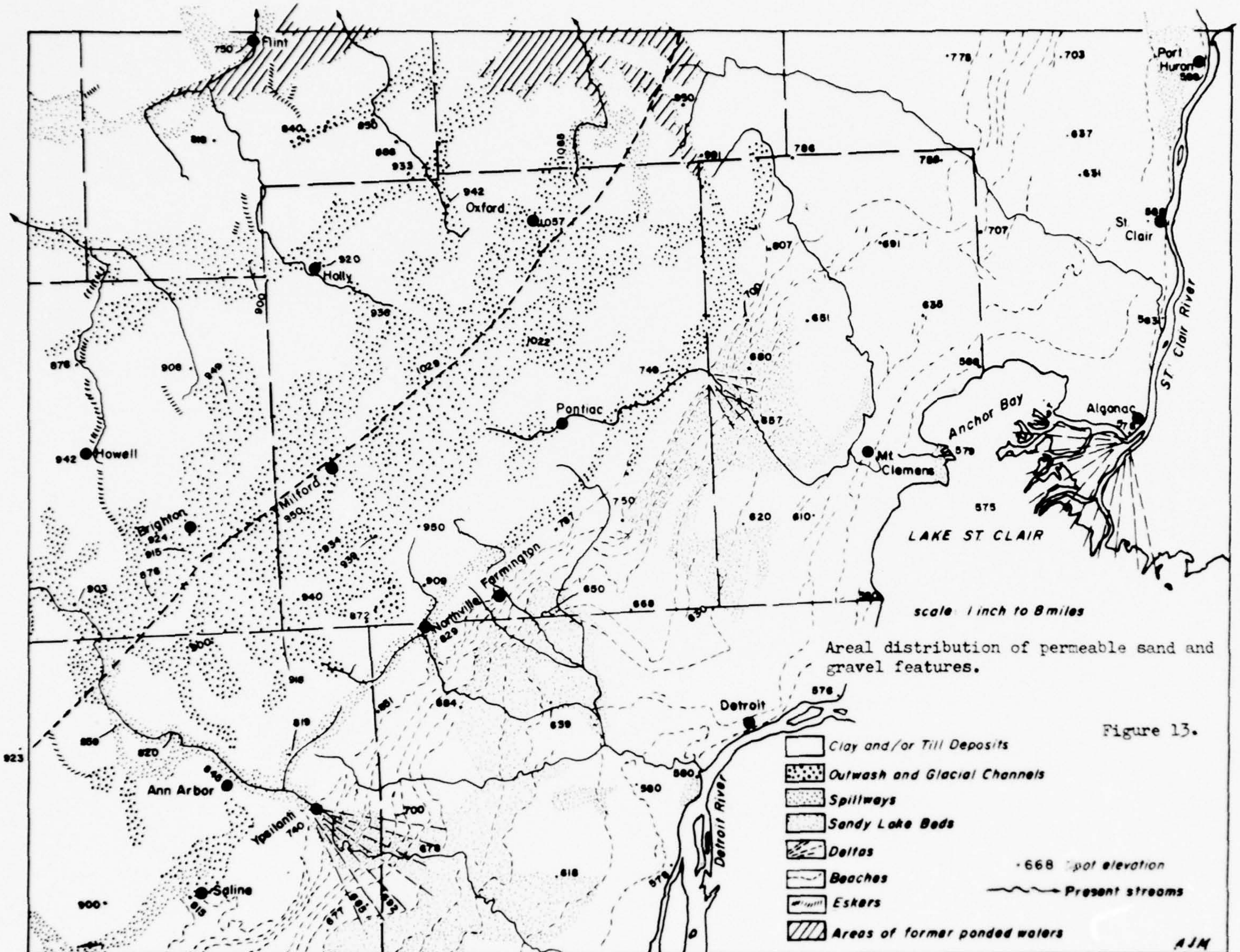
Figure 12: Schematic cross section of unconfined and confined aquifers in glacial drift.

in depth and, in part, water saturated. The level of saturation marks the water-table surface. Such aquifers in the project area are represented by outwash and glacial channels, spillways, deltas, eskers, beaches, and sandy lake beds (Figure 13). Sand and/or gravel bodies that are enclosed within less permeable till or lake clay deposits and occurring below the water-table are classed as artesian, or confined, aquifers. In contrast to the former, confined aquifers are completely saturated with water under pressure so that the water will rise to some level above the upper aquifer boundary when penetrated by wells. When water from a confined aquifer rises in a well to some level above the ground surface it is classified as a flowing artesian well. If it rises to some point between the upper aquifer boundary and the ground surface then such a well is designated as a non-flowing artesian well. A soil boring or test well drilled through the total drift overburden may encounter several confined aquifers each with its own water level (piezometric level) as drilling progresses (Figure 12). The magnitude, depth, and number of these confined aquifers within till features can vary from place to place; their discovery and delineation for water supply development is usually dependent on exploratory drilling often accompanied by geophysical work as well. The relationship of the confined aquifers to each other within the drift section is difficult to visualize, or assess, without a substantial amount of subsurface information. Perhaps in most instances, if not the majority, the individual confined aquifers are not characterized by sharp contacts with the enclosing till as is usually portrayed in cross sections but, rather, are gradational so that they are not as isolated as one might conclude. Another manner by which the confined aquifers in till might be viewed is to consider the distribution of the sand and/or gravel deposits as they occur on the surface today (Figure 13). From this illustration it

can be noted that these more permeable features are not completely isolated from each other but, instead, are interconnected in some manner. Hence, if they are subsequently covered by a less permeable clay-till a system of interconnected confined aquifers is the result.

BEDROCK: The occurrence of ground water in the bedrock formations is essentially under artesian, or confined, conditions which are brought about by permeability differences in the stratigraphic sequence together with the presence of clay rich till deposits over much of the rock surface. In contrast to unconsolidated sediments and the igneous and metamorphic rocks, sedimentary rocks are unusual in that they are characterized, with few exceptions, by both primary (pores) and secondary (joints, fractures, bedding planes) porosities; thus both primary and secondary permeabilities. Both in terms of water storage and transmissibility a wide range of conditions exist within the stratigraphic sequence of the project area. Fine grained clastic rocks (shales, siltstones, fine grained sandstones) have high primary porosities which provide good storage, but the transmissibility of water through these small primary openings is of a very low order. Movement of water in such rocks will be along the secondary openings. Because of their larger grain sizes the sandstones and conglomerates are more functional as aquifers provided their pores are not completely filled with the cementing material which binds their grains together. With an increasing cement content in the coarse clastic rocks, transmissibility of water through primary openings diminishes and, thus, a greater dependence on existing joints, fractures, and bedding planes.

The carbonate rocks, limestones and dolomites, have inherently low primary porosities if they are dense to finely crystalline in texture. Movement of ground water in them is largely controlled by their secondary openings.



Areal distribution of permeable sand and gravel features.

Figure 13.

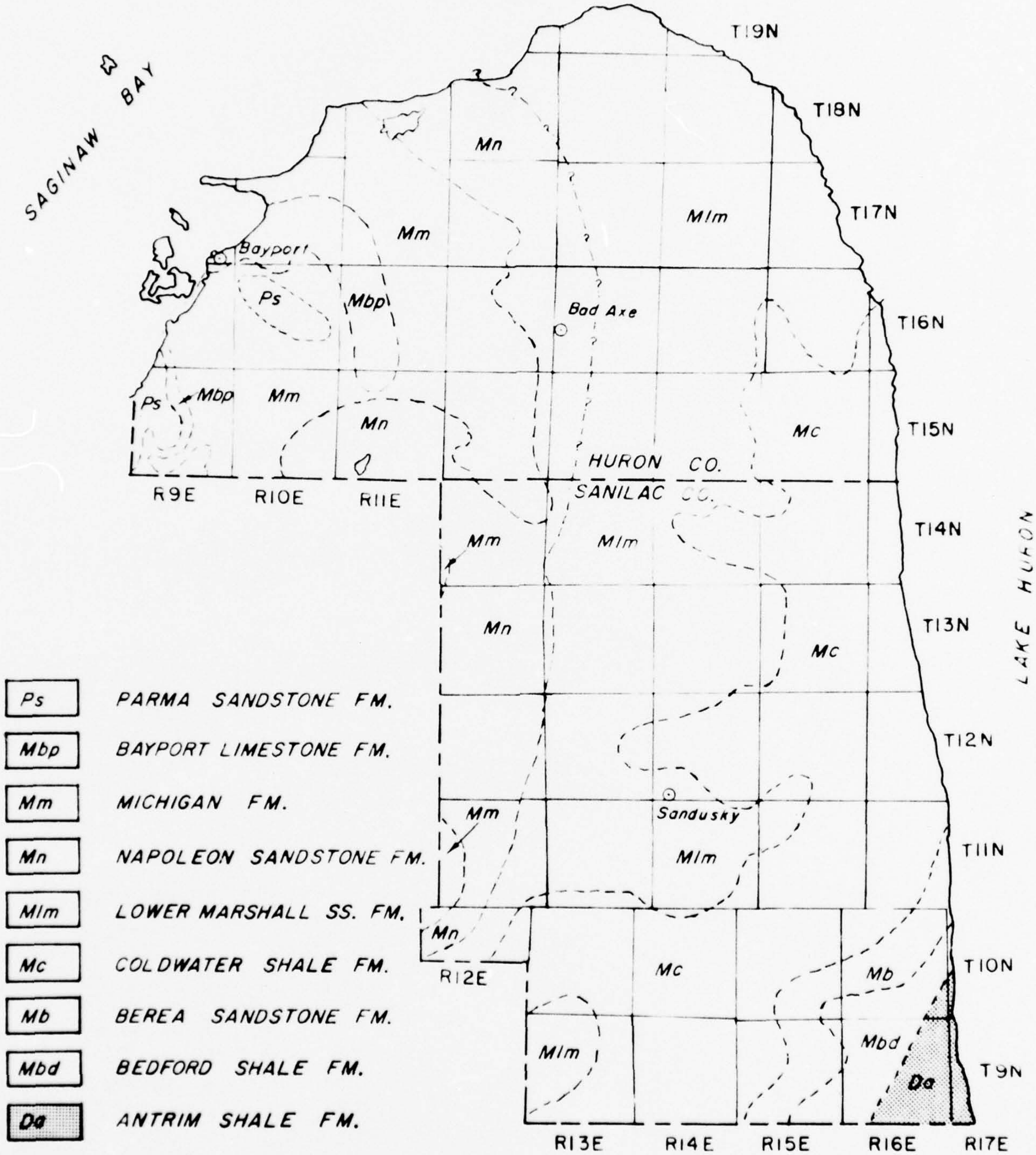
In contrast to the clastic rocks, the carbonates are unique in that they are relatively soluble. Movement of water along existing bedding planes, fractures, and joint systems enlarges them by solution with the net result that permeability increases with time. When carbonate rocks have an effective primary porosity, their function as aquifers is even better since the primary openings provide for the additional storage of water. The solution enlarged openings in limestones and dolomites should be considered as conduits and when intersected during excavation then a copious amount of ground water can be expected as experience has shown.

PROJECT HAZARDS

A. **METHANE GAS**: A major hazard to tunnel construction in the project area is the presence of methane gas, particularly in the Antrim shale, to some degree in the Traverse Group and Dundee formations, and possibly in the Bedford and Berea formations. For the latter two rock units, it is probable that the occasional methane shows reported might represent gas migration from the Antrim shale upwardly in the stratigraphic section. Inasmuch as oil and gas are recovered in commercial quantities from a number of formations, both shallow and deep, in other parts of the state, then the indication of oil and gas shows in the rock strata of the project area should be expected and not come as a complete surprise. Of the proposed tunnel routes most will involve the Antrim, Traverse, and Dundee to some degree as may be noted by plotting the routes on the geologic map for the project area (Plate 1; Figures 14 and 15), or by reviewing the well log summary sheets previously submitted to the Basin Planning Section, U.S. Army Engineer District, Detroit. Some of the tunnel routes will pass through or near producing oil and gas fields shown on a map which has been included in this report.

The presence of methane is also to be expected in the drift overburden especially where it lies in direct contact with the Antrim, Traverse, and Dundee strata. Of the water well records and soil borings for which gas shows were reported (Plate 1) more than 95 percent were completed at some depth in the drift overburden with the remainder reaching or penetrating bedrock. Most of the borings and wells finished in the overburden are contained within the limits of the glacial lake plain area of southeastern Michigan with none located in the morainic areas to the best knowledge of this investigator. However, its presence must not be precluded entirely.

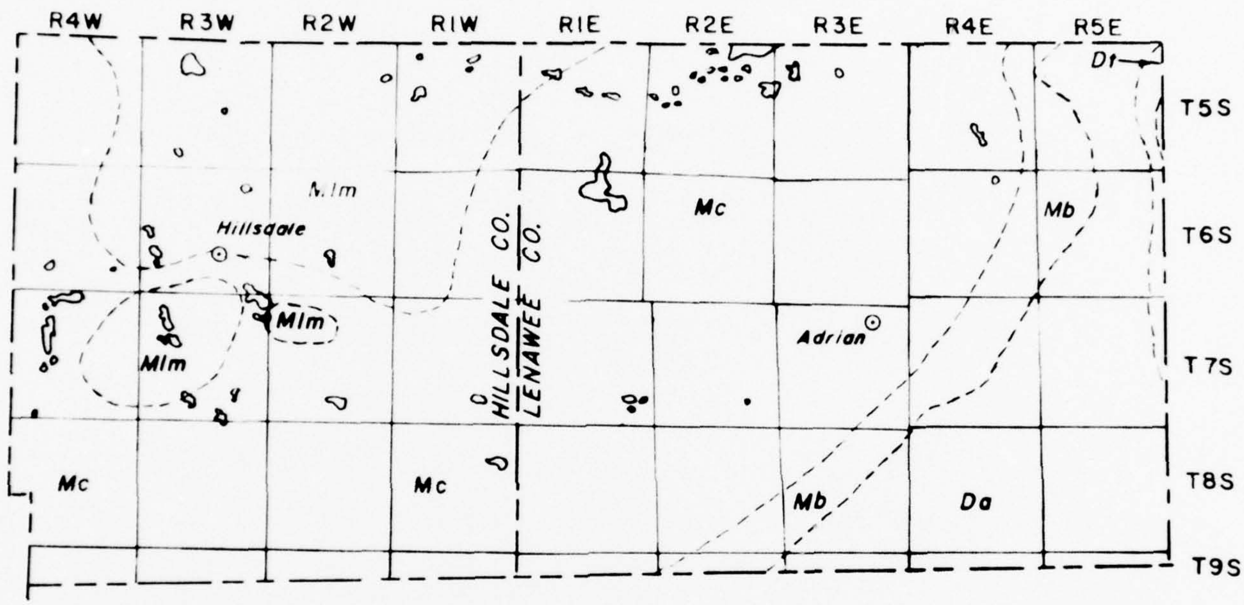
Existing records show that methane gas can be found at any depth within the total drift section. It may occur as "gas pockets" with pressures reported as high as 37 psi or as weak seepages along cut faces. Gas has been found in the drift in sufficient quantity and under enough pressure as to result in gas wells for space heating and cooking purposes. It was not uncommon for such gas wells to become depleted in time with the eventual entry of ground water into the wells. Unless sufficient pressure existed, it can be reasonably assumed that minor gas seepages in wells or borings of the region remained undetected by drillers. A routine check of service lines by a gas utility disclosed the presence of methane at a shallow depth at two school grounds in Oakland County. Sampling and subsequent analyses of gas taken from the soil overburden at depths of 1 to 2 feet disclosed that the gas was not the result of leakage from the underground service lines. Methane has also been detected in a number of basement excavations in several subdivision developments within the limits of the project area. Where present it is most frequently associated with the more permeable but confined sand and/or gravel horizons within the drift overburden. It has also been reported in overburden materials described as hardpan, silt, silty clays, sandy clays,



GEOLOGIC MAP OF SANILAC AND HURON COUNTIES

Scale: 1:500,000 Source: Michigan Geological Survey

Figure 14.



GEOLOGIC MAP OF LENAWEE AND HILLSDALE COUNTIES

Scale: 1:500,000 Source: Michigan Geological Survey

Mlm	LOWER MARSHALL SANDSTONE FM.
Mc	COLDWATER SHALE FM.
Mb	BEREA SANDSTONE FM.
Da	ANTRIM SHALE FM.
Dt	TRAVERSE GROUP

Figure 1[illegible].

stiff blue-gray clays, and clay. It is not uncommon to find methane present along the bedrock-overburden interface. Though gas is present one day, it may be absent at a later date or, perhaps, present in such small concentrations as to fall below the limits of detection with the equipment used. This does not imply that the problem has disappeared, for at some localities gas has reappeared after an absence of several days. Apparently other factors play a part in the presence or absence of gas in the overburden at a specific site, and one of these may be due to changes in the direction of ground water movement and water pressures brought about by water wells operating in the area.

Methane is also associated with ground water regardless of the depth of the aquifer. Well records and other documents show that the gas has been detected or observed as bubbles in natural springs, in shallow dug or driven wells (water-table aquifers), and in flowing and non-flowing wells (artesian aquifers). When associated with ground water the gas/water ratios (percent volume) ranged from 0.3 to 6.6 percent as reported by the Michigan Department of Health. Methane is practically insoluble in water and its association with ground water entering wells, tunnels, or tight excavations constitutes a hazard at all times. Discharge of methane gas bearing ground water from its confinement in the aquifer, along with its subsequent increase in temperature, results in the rapid separation of the gas. Thus, sumps or dewatering wells that are used to keep a working area dry represent a situation in which methane is continuously released. Looking into wells in operation while smoking has led to numerous instances where "whiskers have been singed." Use of test holes for "bleeding" the gas releases the pressure but does not completely eliminate the gas hazard. For tunnels, shafts, and caisson projects there must be adequate ventilation, strict adherence to safety procedures, and reliance on warning devices. Characteristics of methane gas are summarized

below:

1. Composition: CH_4 - Methane
2. Odorless, tasteless, colorless combustible gas
3. Forms explosive mixture with air - 5.6 to 13.5 % by volume
   (a) Maximum flame speed at 9.6% by volume
   (b) Above 13.5% mixture with air gas burns quietly after ignition
   (c) 9.5 cubic feet of air required to burn 1.0 cubic feet of methane.
   (d) In atmosphere of nitrogen, or other inert gas, oxygen must be present at least to the extent of 12.8%.
4. Boiling point -161° C
5. Density 0.72 grams/liter at 0° C and 760 mm of pressure.
6. Specific gravity 0.55 (air equal to 1.00)
7. Practically insoluble in water.

B. HYDROGEN SULPHIDE GAS: This gas can also be present in ground water from both bedrock and glacial drift aquifers. It is a toxic gas with an odor of rotten eggs. Upon initial exposure, the odor is strongly noticeable but with time it becomes progressively less and less noticeable despite the fact that the level of concentration of this gas in the working area has not changed. Continued exposure produces watering and irritation of the eyes, nausea, and in time is fatal. Ground water with hydrogen sulphide is not uncommon in the carbonate sequence beneath Monroe and Wayne Counties.

C. SUBSIDENCE: The extraction of Salina salt by artifical brining techniques has taken place for a number of decades in or near Marysville, St. Clair City, and Wyandotte. This practice has led to the development of chambers within the salt beds which now constitute a subsidence hazard that has already been experienced on two separate occasions. The first occurred some years ago in the Windsor, Ontario area in which a factory was damaged and, more recently, two subsidence craters developed near the extreme north end of Grosse Isle. Whether there have been any indications of subsidence in the Marysville and St. Clair City areas are not known to this writer at the present time. It may be prudent to prepare a map of all known brining wells in the Salina salt for the project area.

D. BRINE DISPOSAL WELLS: Wells for the disposal of oil field and refinery brines also are present in the project area, some of which may be situated near the proposed tunnel routes. Though the writer has no specific knowledge of dates and places, there have been rumors to the effect that in some instances brines were not fully contained within the intended injection horizon and led to local contamination of shallow aquifers. In one instance the appearance of brine at the ground surface occurred. One possible explanation for this may be the existence of old wells, not known to State Agencies, that have been totally abandoned and improperly grouted. For this project it would also be in order to plot all known disposal wells (oil field, refinery, industrial, commercial), their dates of initiation along with injection horizons, rates, and pressures. The latter is particularly significant in that excessive pressure can lead to possible rupturing of rock strata. It also has been documented in the Denver, Colorado area that injection of fluids into the subsurface led to the initiation of earthquake tremors.

E. EARTHQUAKES: Possible damage to structures by earthquakes occurring in the project area is rated as minor. This is based on the "Seismic Risk Map for the United States" issued in 1969 by the U.S. Coast and Geodetic Survey, Environmental Sciences Services Administration, which shows earthquake damage zones of reasonable expectancy within the next century. All of Michigan and adjacent Ohio and Indiana are included in the minor damage zone. Nearest moderate earthquake damage zones are shown for northeastern corner of Ohio and adjacent areas in New York and Pennsylvania. Southwestern Ohio, southern half of Indiana and southern third of Illinois is another zone of possible moderate earthquake damage.

POTENTIAL PROBLEMS DURING PROJECT CONSTRUCTION

A. GROUND-WATER FROM BEDROCK: With respect to the clastic sequence that is

above the Traverse Group, ground water problems in the course of tunneling will most likely be minimal except where (1) carbonate rock and sandstones, (2) highly fractured and/or highly weathered rocks are encountered along the route. Abandoned, poorly grouted wells and brine disposal fields may also contribute to water problems. The carbonate rock sequence below the Traverse, which occurs in outcrop beneath the soil overburden over much of Wayne and Monroe Counties, should be considered most likely of discharging copious quantities of ground water during construction. Evidence for this is suggested by the following:

(1) Sink Holes: The presence on the surface of these funnel-shaped depressions with gentle slopes reflects the effects of ground water solution of carbonate rocks along joints, fractures, and bedding planes. They attest to the presence of subterranean passageways which function as conduits which may be completely or partially filled with water (Figure 16). During the wet season the sinks may contain water and thus temporarily are sink hole lakes (Figure 17). One such lake appears in Monroe County near the village of Ottawa Lake. Depressions in carbonate rocks which are deep and characterized by steep sides are termed "collapse sinks" and represent rock failure at points along subterranean passageways. To the writer's best knowledge there are no positively known collapse sinks in Monroe County which might indicate the existence of a large underground cavern system. Solution sinks are known in southwestern Monroe County where the soil overburden is relatively thin. In one instance, a sink hole was uncovered in the course of overburden stripping operations at a quarry site just south of the city of Monroe. The occasional, low, bedrock elevations that are obtained from driller's logs could be associated with sink hole features and not always with bedrock valleys.

(2) Springs and Flowing Wells: Geologic publications dating back to 1910-1920

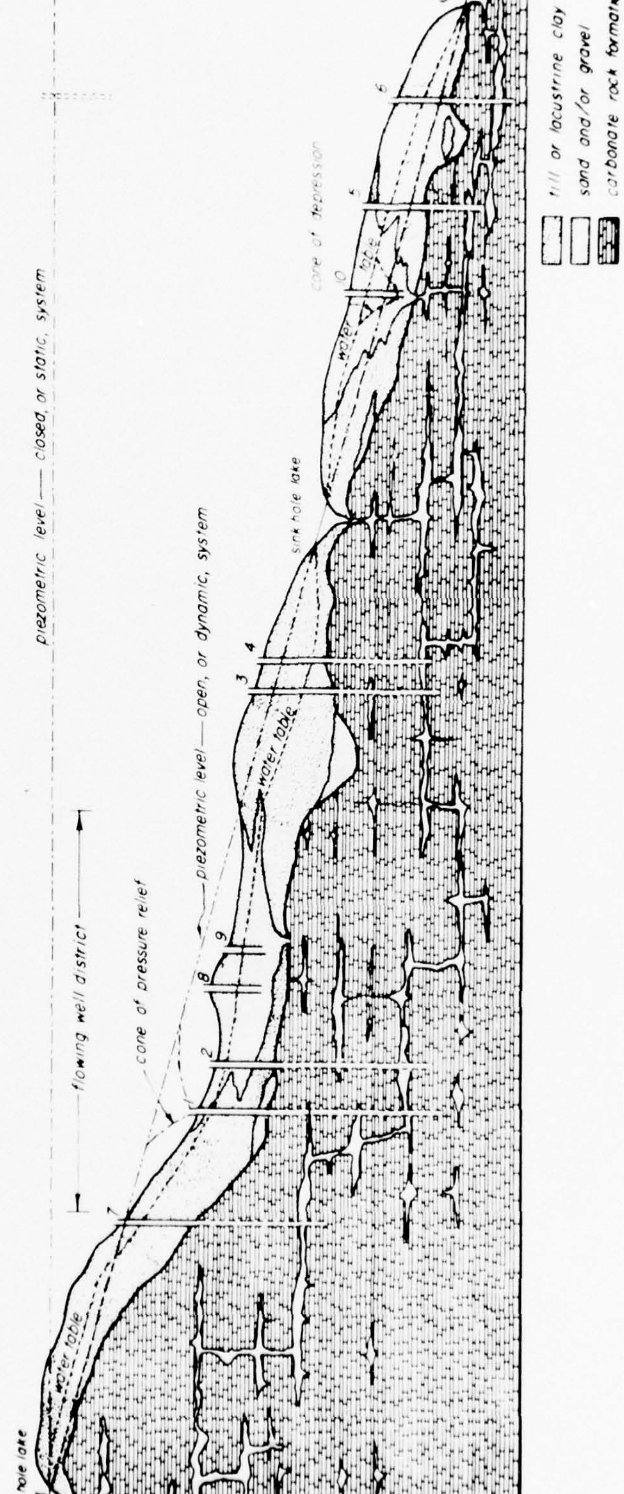


Figure 16: Schematic diagram of Ground Water Occurrence in Carbonate Terrain and Overlying Drift.

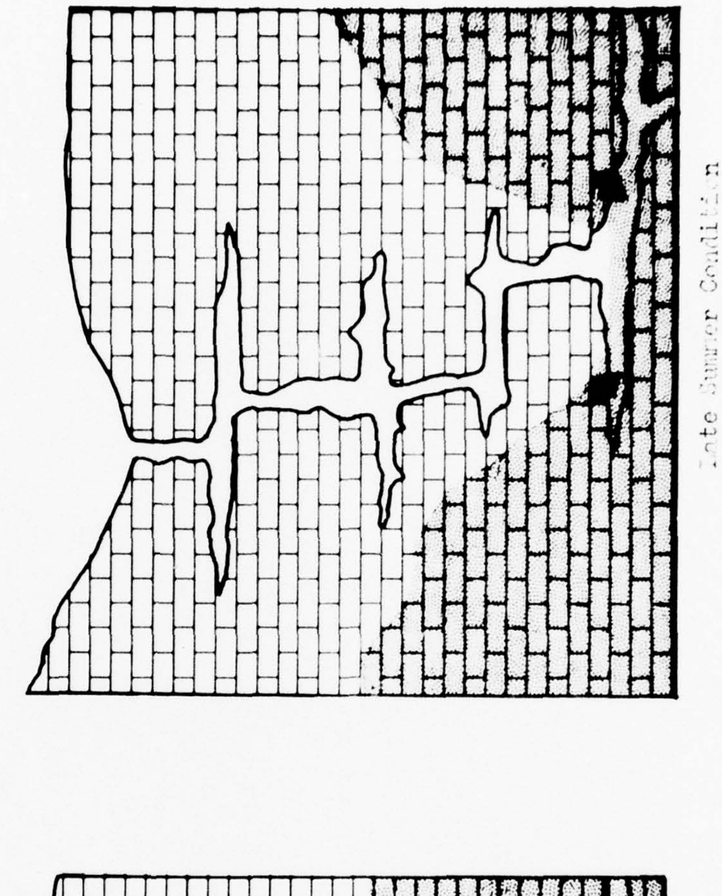


Figure 17: Sink hole and sink hole lake.

report the occurrence of springs with strong flows along the shore line and adjoining marsh areas in Monroe County. Flowing well districts were also common along the Huron River and in areas marginal to the Lake Erie shore line (See Piezometric Water Level Map of Monroe County).

(3) Water Well Records: A number of these records, particularly in Monroe County, bear driller's references to "water seams" one-quarter to one inch in magnitude.

(4) Rock Boring Reports: More recently, deeper borings into bedrock in northeastern Monroe County report occasional "voids" or "chambers" one-half to two feet in magnitude at various depths, with the deepest at 115 feet. In addition the rocks are often highly vugular, fractured, and/or brecciated. Ground water in association with these rocks is reported high in hydrogen sulphide.

(5) Construction Projects: Copious quantities of ground water were discharged during caisson construction at the water treatment plant in northeast Detroit and, again, at a new quarry site located in the southeastern corner of Washtenaw County. At the quarry site a strong flow was encountered in the carbonate rocks immediately below a 10-20 foot shale section of the Traverse. Ground water had a strong odor of hydrogen sulphite.

B. GROUND WATER IN DRIFT OVERBURDEN: Whether water problems will be encountered during project phases involving such materials will depend largely on the magnitude and permeability of the unconfined and/or confined sand/gravel aquifers that are present at the particular construction site. Instances of excessive ground water discharge from the drift overburden have occurred in the southeastern Michigan area in the past. Dewatering methods are normally applied where grouting was unsuccessful or deemed as uncertain. Application of the soil freezing technique may be necessary if water saturated silts or

very fine sands are intercepted during excavation. Such water saturated materials can flow into a cut at a considerable rate and measures to meet these situations should be included in planning. That such materials may be present in the subsurface is usually indicated on driller's logs as "sand flows" or simply "heaving". This should not be considered as a rare situation in a soil overburden of glacial origin.

C. BURIED BEDROCK VALLEYS: Unless the bedrock profile along the proposed tunnel routes are known in detail, there remains the inherent danger that a drift-filled bedrock may be unexpectedly intersected during excavation (Figures 18, 19, 20). There is no assurance that the deepest rock valleys have been recognized on the basis of existing subsurface data. Bedrock lows along the proposed routes can serve as sites for the shafts needed in tunnel construction.

D. BOULDER CONCENTRATIONS: For tunneling in drift, consideration should be given to the possible existence of boulder concentrations in the soil overburden which may not be indicated by the soil samples and boring logs. One instance is known to this writer where a high boulder concentration has rendered the tunneling machine useless, requiring manual labor for their removal thereby causing considerable delay in the project completion date. The objective in mind is the avoidance of possible litigations on the grounds that borings furnished the contractor did not indicate the true character of subsurface materials along the tunnel route.

E. EFFECTS OF DEWATERING: Dewatering procedures needed to keep a working area reasonably dry during construction will locally affect the water level of both water-table and artesian wells. This will initiate complaints of well failures or decreased well performance by residents. Observation wells might be required to determine the size of the cone of depression or cone of

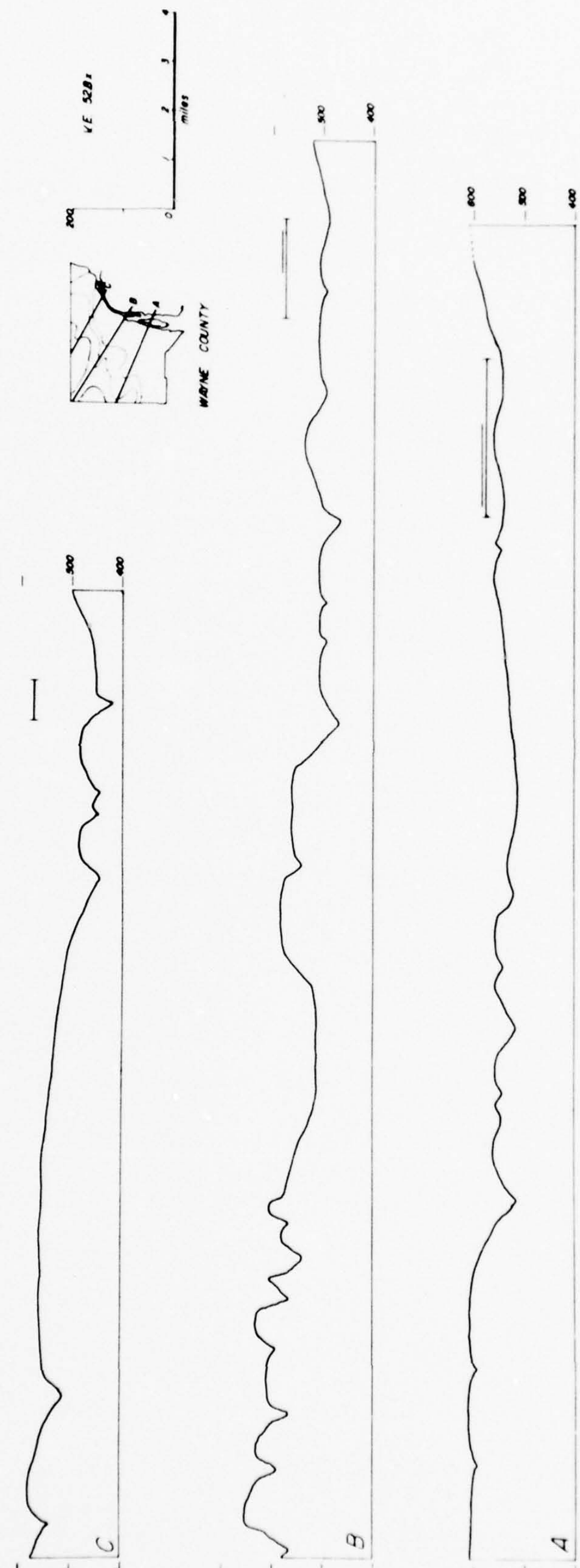


Figure 18: Northwest-Southeast Bedrock Profiles in Wayne County, Michigan.

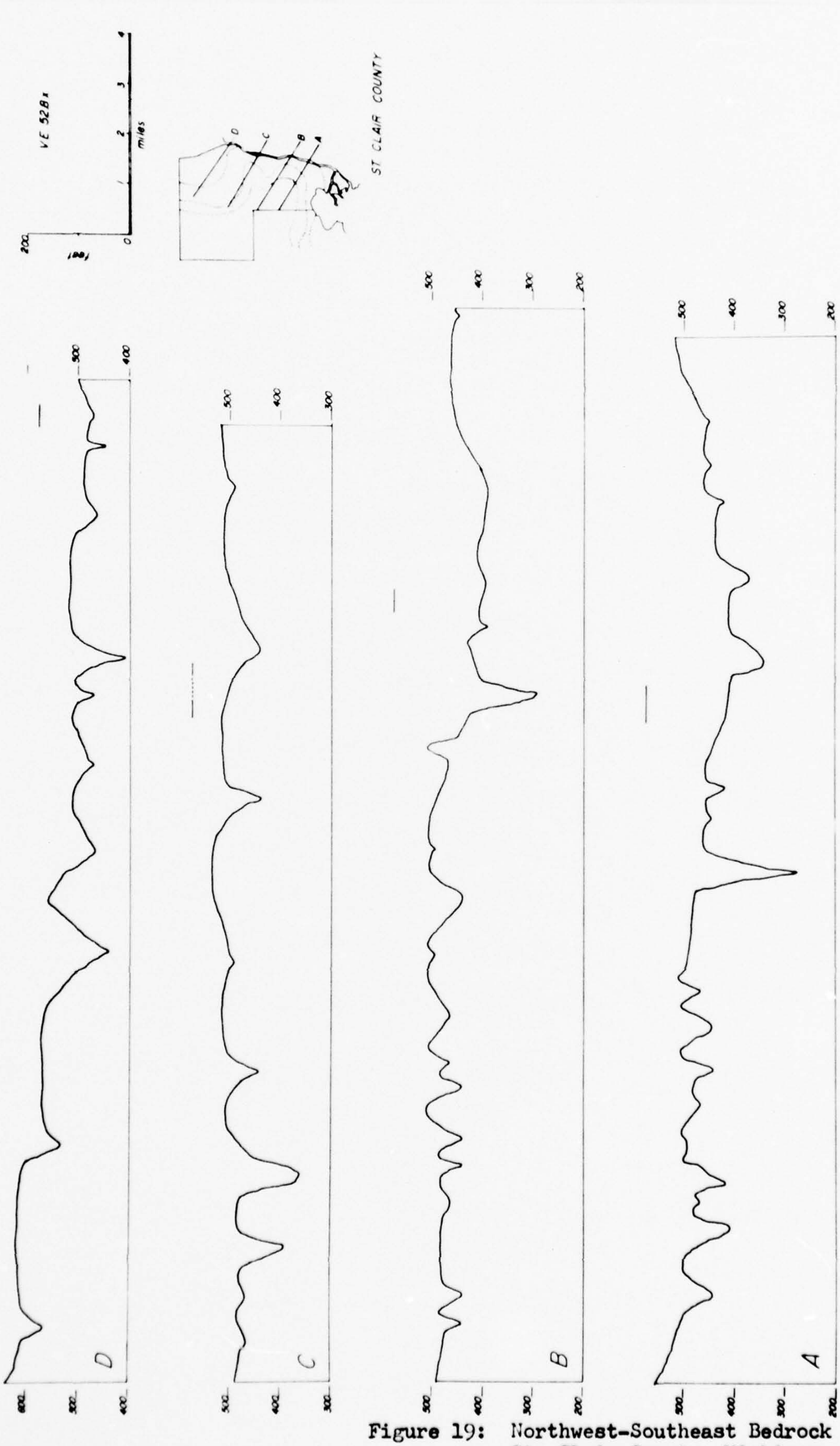


Figure 19: Northwest-Southeast Bedrock Profiles in St. Clair County, Michigan.

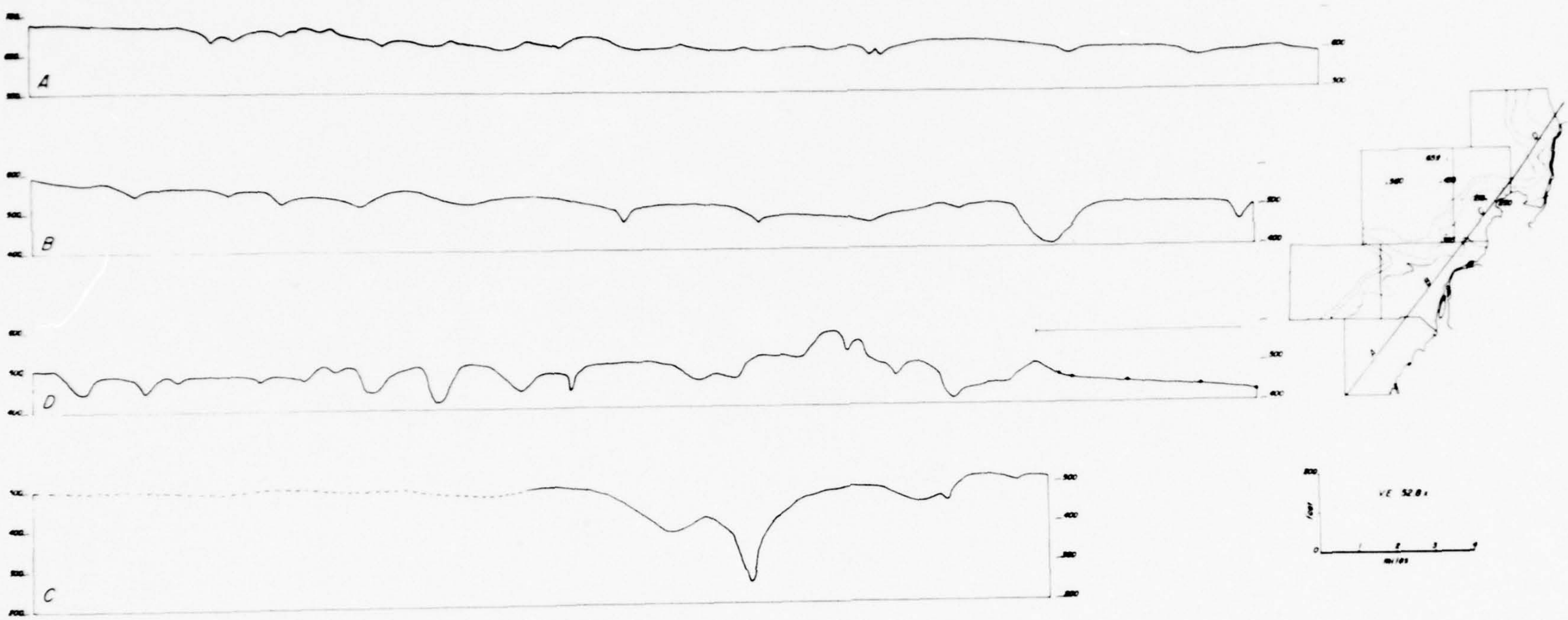


Figure 20: Northeast-Southwest Bedrock Profile thru St. Clair, Macomb, Wayne, and Monroe Counties, Michigan

pressure relief, whichever is the case, in order to honor just claims. Cessation of dewatering procedures will result in the recovery of the cone unless dewatering has been at an excessive rate over an extended period. If so, some compaction of the aquifer involved may occur.

F. EFFECT OF OPEN CHANNEL CUTS: Depending on depth of cut, the gradual dewatering of water-table and artesian aquifers can occur as has been the case in some areas during expressway construction. If open channels are to be lined with concrete, or some other less pervious material, consideration must be given to the effects this will produce on ground water levels.

G. EFFECTS OF HOLDING PONDS: Since few materials in nature are totally impermeable, holding ponds will result in the development of ground-water mounds which will locally modify the water-table surface and thereby direction of ground water flow. The ground-water mound in itself may not be a deleterious feature, but rather the effect of the waste water on the quality of ground water with time. To reduce waste water leakage liners may be required for the holding ponds. These may be of clay, concrete, or asphalt. More recently some success in significantly reducing leakage has been achieved with synthetic polymers blended with bentonite clay (Dowell Division of Dow Chemical Company).

GEOLOGICAL SURVEY ALONG TUNNEL ROUTES

From the preceding discussion it is evident that the basic geological document for tunnel design and construction is a geological profile along each of the proposed routes. These profiles should depict in detail the bedrock and overburden lithologies, formation contacts, bedrock topography, faults, joint systems, and zones of weak rock due to fracturing and/or weathering. Any unusual water seepages or hazards should likewise be shown or indicated on the profile as well as on the accompanying geologic map. Except for a few quarries in Wayne and Monroe Counties, the bedrock surface is hidden from view

by a soil overburden and, therefore, the mapping of the rock topography and outcrop delineation of the rock units necessitates the use of subsurface information which is generally obtained from soil and rock borings, oil, gas, and water well records. Though this information is available, the density and distribution of the records are such that it is inadequate for the project under consideration. Furthermore, there is a wide variation with respect to the details and quality of information shown on each record. Compilation of the geological profile will necessitate test borings, core drilling as well as geophysical surveys. The latter will be useful as a means of obtaining information relative to (1) the depth of bedrock between test hole sites, (2) extent of faults, fractures, joints, and highly weathered rock zones, and (3) the recognition of particular beds as stratigraphic reference horizons and their possible intersection with the invert grade of the proposed tunnels.

TEST DRILLING PROGRAM

A. SPACING OF TEST BORINGS: Initially, borings could be spaced at one mile intervals and followed by geophysical surveys between these points at one-quarter or one-eighth mile stations. A second set of borings may be required at half mile stations to verify geophysical interpretations and to obtain additional subsurface data. Additional closely spaced borings will be required where unsound geologic conditions are suggested and at sites selected for shafts to serve as portals for tunneling. The latter borings may have to extend beyond the tunnel invert to furnish data for proper portal shoring and foundations.

B. DEPTH OF BORINGS: At least to depth of the tunnel invert. If boring site is situated over a deep unmapped rock valley then boring should be extended to the top of the bedrock surface. Penetration into the rock for some

depth may be desirable if the particular boring site could serve as an alternate shaft.

C. SAMPLES - SOIL OVERBURDEN: Split spoon samples should be taken at regular, or at such, intervals as to be representative of the total overburden. For surface structures along the proposed tunnel routes additional samples may be required for foundation design. These should be clearly specified in the boring contracts.

D. SAMPLES - BEDROCK: By core drilling from bedrock surface to invert depth of tunnel. Notes on percentage of core recovery per run, as well as time required for run, should be noted on boring record. Diameter of core at least 4 inches; preferably greater economics permitting. The core samples and recovery notations are useful in indicating (1) whether the material is hard or easy for tunneling, and (2) where tunnel supports may be required. As a general rule, with new and improved tunneling machine nearly all hard massive rocks excavate readily and may stand without support except where highly deformed, faulted, and fractured during past movements of the earth's crust. As hardness decreases, the workability of the rock improves but their stability decreases. This is especially true of decomposed rock materials.

Existing data on unconfined compressive strengths for the uppermost portion of the Traverse Group (ranging from 1100 Psi to 28,400 Psi) have been submitted to the Soil and Foundation Unit of the U.S. Army Engineer District, Detroit. The Unit has also arranged for some unconfined compressive strengths on existing rock cores in storage representing the following rock units.

Rock Unit	No. of Samples	Range (Psi)
Saginaw Formation	4	2,603 - 5,395
Antrim Shale	3	5,127 - 8,252
Traverse	3	4,902 -17,287
Dundee Limestone	3	5,178 - 7,171
Detroit River Dolomites	4	1,056 -13,529 (1)

Sylvania Sandstone	6	2,378 - 7,834
Bass Islands Group	11	2,889 -14,539 (2)
Salina (upper)	2	6,853 -10,924

(1) Low value from sample described as "gray, vuggy limestone."
(2) Whether Raisin River dolomite or Put-in-Bay dolomite not specified.

The cores, aside from providing a detailed lithology, will also provide samples for unconfined compressive strength tests, physical and chemical analyses. The latter two tests could determine the suitability of the limestones and dolomites as aggregate material for concrete; the last test for delineating high calcium limestones which may be a saleable item to the cement industry (plants in Port Huron, Detroit, and Dundee). Physical and chemical analyses of shale samples would establish their swelling characteristics, hence, problems that might arise during excavation and, in addition, determine their possible use as a raw material for cement making and/or light weight aggregate production.

<u>E. WATER LEVELS - SOIL OVERBURDEN</u>: To be measured at first occurrence and each time a confined aquifer is penetrated as drilling proceeds. Hole should be cased down to, or slightly into, the top of the aquifer before measurement is made. Depth of casing, or boring depth, should be indicated after each water level shown on the final log.

<u>F. WATER LEVELS - BEDROCK</u>: After initial reading of water level with casing on top of, or slightly into, rock there should be periodic readings taken, perferably after each coring run, to establish whether the water level is rising or falling with depth. Final water level upon completion of hole to invert depth of tunnel. If a strong head is indicated a pump test may be advisable to estimate ease or difficulty in lowering water level to the invert depth of tunnel or to some point below.

<u>G. WATER SAMPLES</u>: To be taken from bedrock and drift aquifers and analyzed

for those parameters which may adversely effect tunnel linings or concrete structures placed below the water table.

H. METHANE GAS: Checks for methane should be made in both overburden and bedrock with an explosemeter as drilling proceeds. Slow seepages may remain undetected and for this reason it is suggested that a final check be made after the completed hole has been capped for a period of 12 to 24 hours. Drill crews should be warned against possible "blows" or exposions; not to look into the hole while smoking.

I. GEOPHYSICAL LOGGING OF TEST HOLE: Recommended as an aid to the recognition of formation tops, water saturated horizons in rock, fractured and weathered zones.

J. LOGGING WITH BORE HOLE CAMERA: Provides a picture record of formation dips, intensity of joints and fractures, and general appearance of rock in place. Compass orientation is automatically recorded on film thereby allowing determination of strike, dip, and tops of the rock units.

K. LOGS: Should bear detailed notations of any unusual conditions as drilling progresses - sand flows (heaving), boulders encountered in overburden and whether an offset was necessary. In bedrock, drilling time per foot of penetration is an important notation.

L. GRAPHIC LOGS: To be prepared at a suitable scale for each hole showing the lithologies penetrated, formation tops, faults, and flexures. Graphic logs are then adjusted to the datum used for final preparation of the geologic profiles, maps and reports for each of the proposed tunnels.

TUNNEL LININGS

Use of linings will add considerably to the total project costs, and any decision to exclude it in whole, or in part, for reasons of cost should take the following into consideration:

A. Since the proposed tunnel routes will be at depths below the water table, it will be necessary to evaluate the flow of ground water into them. If the rate of infiltration is significant pumping may be required to maintain an adequate capacity for the tunnels to receive storm water run-off. Leakage will most likely be minimal where tunnels are in shale but the same may not be true for tunnels completed in the carbonate rocks because of the possible existence of solution enlarged openings. There is no assurance that grouting will be successful and, if so, then what measures will be necessary to prevent the development of new solutional openings by ground water with time?

B. Without tunnel lining there is a good potential for pollution of bedrock aquifers through leakage of waste water from the tunnels. This is particularly true for Monroe County where bedrock wells for domestic, commercial, and industrial water supplies are in use and will be for some decades ahead. Heavy ground water withdrawal by wells does modify hydraulic gradients. Reversals created in the vicinity of a tunnel will induce flow of contaminated water from the tunnel into bedrock in the direction of the pumping well, or wells. Should it be assumed that the entire area will be served by the Metropolitan Detroit Water Supply System, a question is raised as to whether this justifies the pollution of the ground water resource which today is considered an extremely important reserve in the thinking of many experts in both public and private sectors.

C. An unlined tunnel implies the exposure of rocks to weathering under a variety of conditions from full to empty, or nearly empty, conditions. Rocks of many different lithologies, along with subtle variations, are involved. Construction of the tunnels will result in some rock expansion which can produce minute insipient fractures thus permitting entry of air or water into them. This increases their potential for breakdown both chemically and physically. Shales when freshly excavated appear sound and massive, but after some

exposure to air and water they disintegrate, usually parallel to bedding, into platy fragments. Once constructed, what are the possible problems and cost for maintaining unlined tunnels through rocks of considerable diversity? On the other hand, data collected on the chemical quality of both ground water and waste water does permit experimentation and design of a tunnel lining that could resist deterioration to a much greater extent than exposed bedrock.

GEOLOGIC DATA SOURCES

For the preliminary engineering phase of the waste water management study, subsurface geologic information was submitted for the following proposed tunnel routes:

A. Port Huron to Algonac Tunnel*
B. Clinton River - Jefferson Avenue Tunnel*
C. Upper Rouge River - Telegraph Road Tunnel*
D. Rouge River Tunnel*
E. Six Mile - Conner Creek Tunnel*
F. Macomb County to Huron County Tunnel**
G. Monroe County to Hillsdale County Tunnel**

*Ayres, Lewis, Norris and May, Consulting Engineers, Ann Arbor, Michigan.
**Bauer Engineering Co., Consulting Engineers, Muskegon, Michigan.

For proposed tunnels A through E, bedrock topography, structure, and gross lithologies of the rock units involved were plotted on topographic profiles furnished by Ayres, Lewis, Norris and May. Data sources used in the preparation of these profiles included oil, gas, water well records and soil borings along with geologic reports and maps, published and unpublished, dealing with bedrock topography and stratigraphy. For routes F and G, only raw data (well logs) and overlays depicting bedrock topography along portions of these routes were submitted to Bauer Engineering Company due to time limitations.

Since this initial effort, oil and gas logs, occurring along or within two miles of the proposed tunnel routes, have been reproduced and collated according to townships and sections within. For each township a map was included to show approximate location of the logs. A quick review of these logs will

reveal that there is a considerable variation in the details reported, particularly with regard to lithologic descriptions and in the delineation of the rock units represented in the subsurface. It will also be noted that the density and distribution of these records along the routes leaves much to be desired and, hence, does not provide the detailed subsurface information necessary for tunnel construction.

To make these data as useful as possible for this phase of the project, Summary Sheets of the oil and gas logs were prepared for each township, a sample of which is included in this report to facilitate comments about each of the columns shown:

LOG NUMBER: Logs are in numerical sequence for reference to a specific record and identification on township plat maps. The last number represents the number of logs available along or near that segment of the tunnel route.

LOCATION: With some exceptions, location descriptions are based on the U.S. Land Survey Grid System and given usually to the second (40-acre tract) or third quarter (10-acre tract) for the specified section of land within the township. Lineal measurements are also given to pinpoint the given record tract. Thus, "2055N and 1320E" should be read as "2055 feet from North and 1320 feet from East line of quarter section".

TOPOGRAPHIC ELEVATIONS: This value represents the datum used for obtaining all other elevations that are shown for the particular record. Although the elevation appearing in this column is in reference to a sea level datum, it is not necessarily the ground surface elevation for the particular log. It may represent the elevation of the rig floor or Kelly bushing of the equipment used in drilling. More recently oil and gas records show two or three elevations (Ground Surface, Rig Floor, Kelly Bushing) one of which is designated as the datum to be used in determining formation tops.

DRIFT THICKNESS: Value shows amount of soil overburden before bedrock is reached. Unless the ground surface elevation on the log is designated as the datum, this value is not the true thickness and must be corrected. For older records this may not be possible.

BEDROCK ELEVATION: Represents elevation of the bedrock surface obtained by subtracting drift thickness from the datum designated on the log.

Except for the "Remarks" column, the remaining columns represent the stratigraphic sequence of rock units in an order from youngest to oldest across the page. For each rock unit the DEPTH TO, THICKNESS, and ELEVATION OF TOP are shown. Since the interface between the soil overburden and the bedrock represents an erosional surface, it should be understood that the total THICKNESS and ELEVATION OF TOP cannot be given for the first rock unit that is in outcrop beneath the overburden. Thus, for the BEDFORD FORMATION (Figure 21) the value shown under DEPTH TO represents the depth to the rock surface and not the formation top since the latter has been previously eroded. The "R" shown after the thickness figure indicates the number of feet "Remaining" before the next rock unit is encountered. The "E" shown under ELEVATION OF TOP implies that the upper boundary of the rock unit does not exist at that particular point because it has been eroded away. For all other rock unit columns the figures represent the true depth to the particular rock unit, total thickness of the unit, and the elevation of the top boundary of the unit. In some instances, two or more rock units on some logs have been included as a single entry with no differentiation as to formation tops. Such instances on the Summary Sheets are indicated by the letters "N.D." signifying that the formation tops on the logs were not delineated or determined. The "N.R." shown for a particular unit implies that it was not recognized in the subsurface for one or more reasons.

Township Summary Sheets accompanied by plat maps and logs have been previously submitted to the U.S. Engineer District, Detroit, for each of the tunnel routes previously listed with the exception of the Six Mile - Conner Creek route for which subsurface data was not available. The summaries and attached logs should assist those that will be engaged in the test drilling program.

OIL & GAS LOG SUMMARIES FOR ROCK UNITS SHOWN.

COUNTY: St. Clair
TWP: East China T. 4N R. 17E

LOG NO.	LOCATION QUARTERS / DISTANCE (1)	SEC. NO.	TOPO. ELEV (2)	DRIFT THICKNESS	BED ROCK ELEV	Bedford DEPTH TO	Bedford THICKNESS	Bedford ELEV TOP	Antrim DEPTH TO	Antrim THICKNESS	Antrim ELEV TOP	Traverse DEPTH TO	Traverse THICKNESS	Traverse ELEV TOP	Dundee DEPTH TO	Dundee THICKNESS	Dundee ELEV TOP	Detroit River DEPTH TO	Detroit River THICKNESS	Detroit River ELEV TOP	REMARKS
1	(3)	6	590.0	153	437	153	152?	E	305	195	285	500	260	90	760	ND	-170	ND	ND	—	Top Sylvania -570 Top Bass Isl. -755
2	(3)	6	614.0	145	469	145	165R	E	310	202	304	512	238	102	750	ND	-136	ND	ND	—	Top Bois Blanc -551 Top Bass Isl -721
3	S½-SW-SE 424 S - 320 W	7	605.8	187	419	187	[illegible]	E	278	214	328	492	240	114	732	128	-126	860	340	-254	Top Bois Blanc -534 Top Bass Isl -678 Top Salina -844
4	NE-SE-NW 990 S - 100 E	19	594.0	156	438	156	96R	E	252	213	342	465	230	129	695	ND	-101	ND	ND		Top Bass Isl -666

NOTES: (1) Example 990N - 330W to be read as "990 FT. FROM NORTH AND 330 FT. FROM WEST LINE OF QUARTER SECTION
(2) ALL ELEVATIONS — SEA LEVEL DATUM.
(3) See log

PAGE 1 OF 1

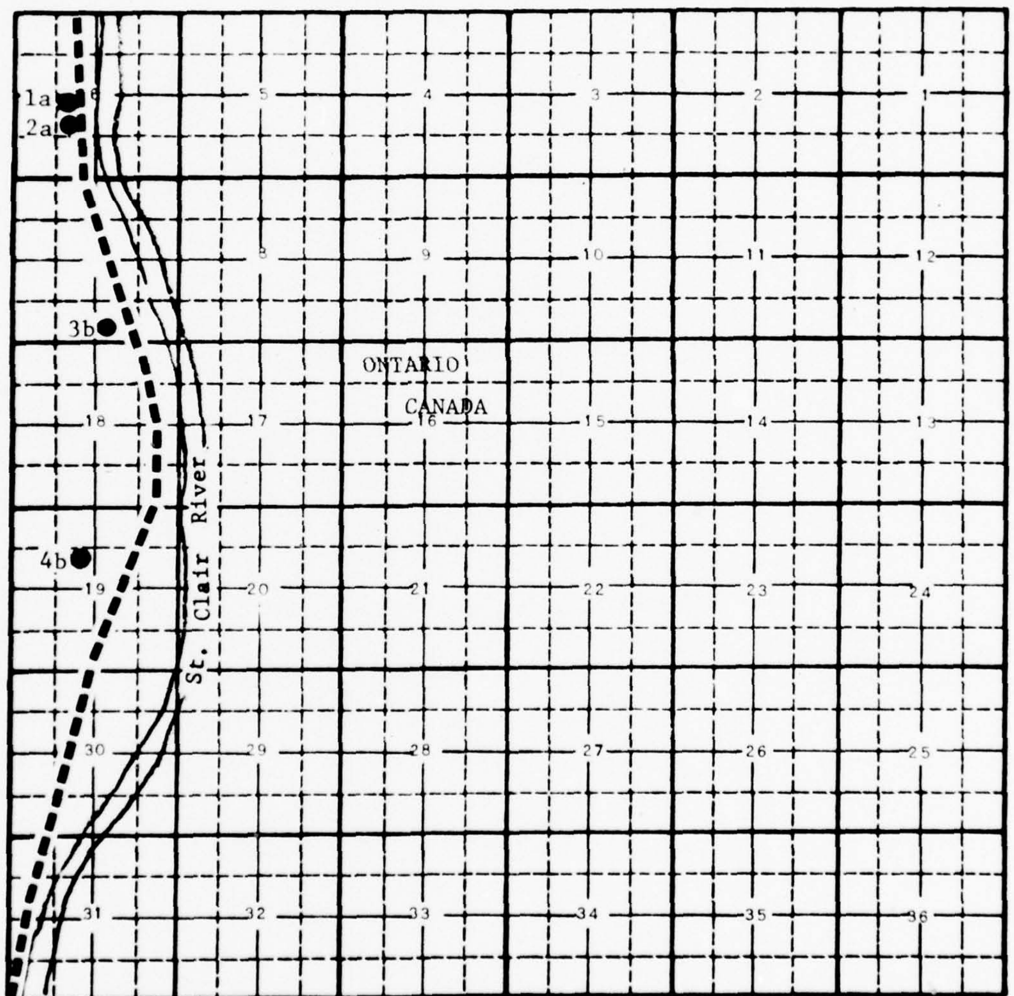
Figure 21: Oil and Gas Log Summary Sheet.

TOWNSHIP 4N **RANGE** 17E **COUNTY** ST. CLAIR **STATE** MICHIGAN

NOTES: PORT HURON TO ALGONAC TUNNEL

EAST CHINA TWP

T-4N



T-4N

R-17E
EAST CHINA TWP

▬ ▬ ▬ Proposed Tunnel Route
a Boring Location Approximate (Private Claim or Poor Description)
b Boring Location - U.S. Land Survey Grid.

Figure 21A: Township Plat Map showing location of existing oil and gas logs along proposed tunnel route.

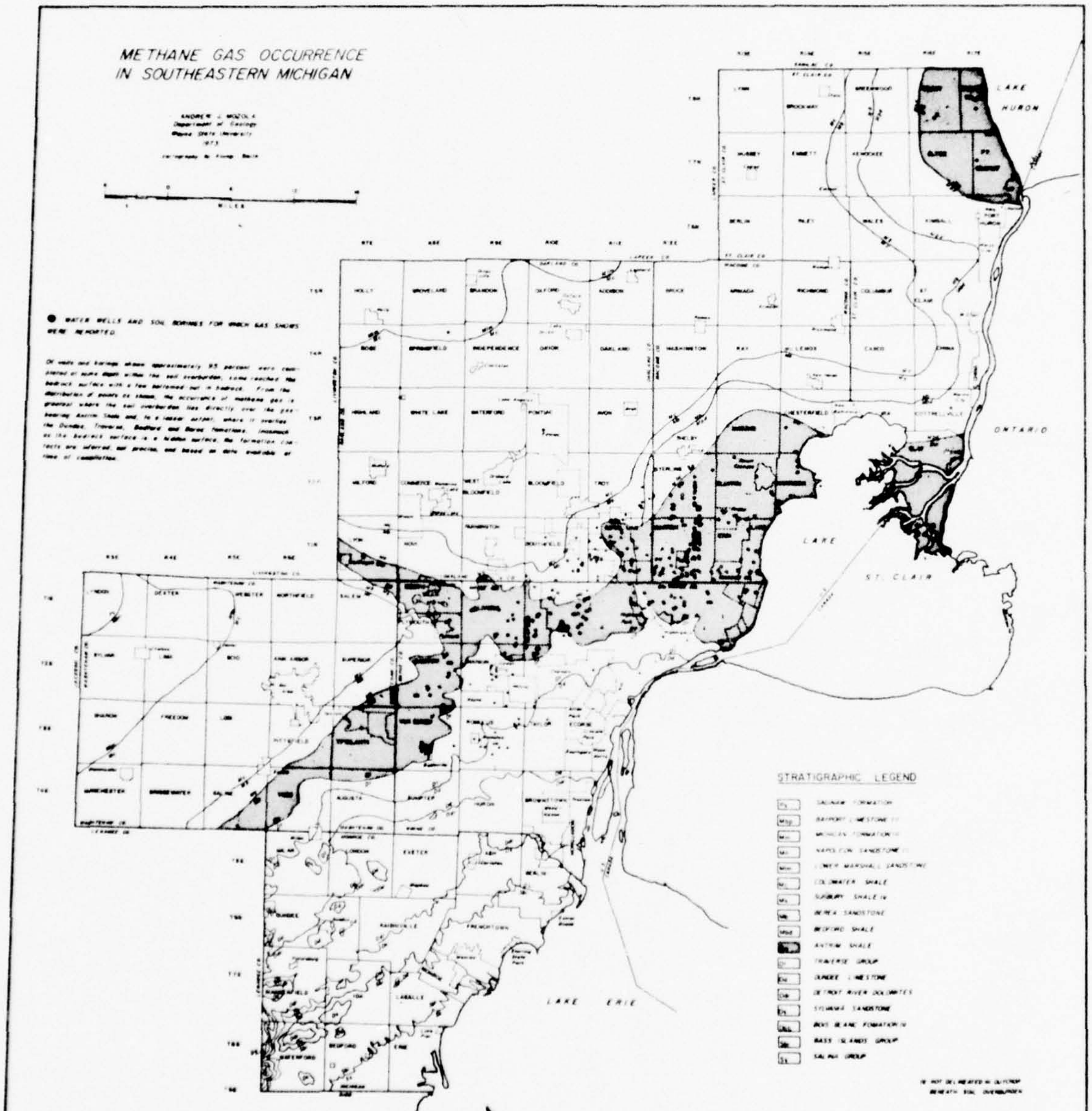

METHANE GAS OCCURRENCE
IN SOUTHEASTERN MICHIGAN
ANDREW J. MOZOLA
Department of Geology
Wayne State University
1973
MILES
WATER WELLS AND SOIL BORINGS FOR WHICH GAS SHOWS WERE REPORTED
LAKE HURON
ONTARIO
LAKE ST. CLAIR
LAKE ERIE
STRATIGRAPHIC LEGEND
SAGINAW FORMATION
BAYPORT LIMESTONE
MICHIGAN FORMATION
NAPOLEON SANDSTONE
LOWER MARSHALL SANDSTONE
COLDWATER SHALE
SUNBURY SHALE
BEREA SANDSTONE
BEDFORD SHALE
ANTRIM SHALE
TRAVERSE GROUP
DUNDEE LIMESTONE
DETROIT RIVER DOLOMITES
SYLVANIA SANDSTONE
BASS ISLANDS GROUP
SALINA GROUP

PLATE 1.

APPENDIX A

PROJECTED TUNNEL ROUTES

The following Appendix A shows a geologic examination along tentative tunnel routes compiled during the Southeastern Michigan Wastewater Management Study. Existing well records were examined to determine the depth and somposition of the overburden, and the geology of the various rock strata. This included records showing the possibility of the existence of gas.

The legend shown below describes tentative tunnel routes and existing boring locations. It applies to every sheet in this Appendix.

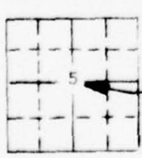
▬ ▬ ▬ ▬ ▬ PROPOSED TUNNEL ROUTE

▲ BORING LOCATION APPOXIMATE (PRIVATE CLAIM OR POOR DESCRIPTION)

● BORING LOCATION - U.S. LAND SURVEY GRID

●3 ▲3 BORING IDENTIFICATION NUMBERS

⬤ CITIES AND TOWNS

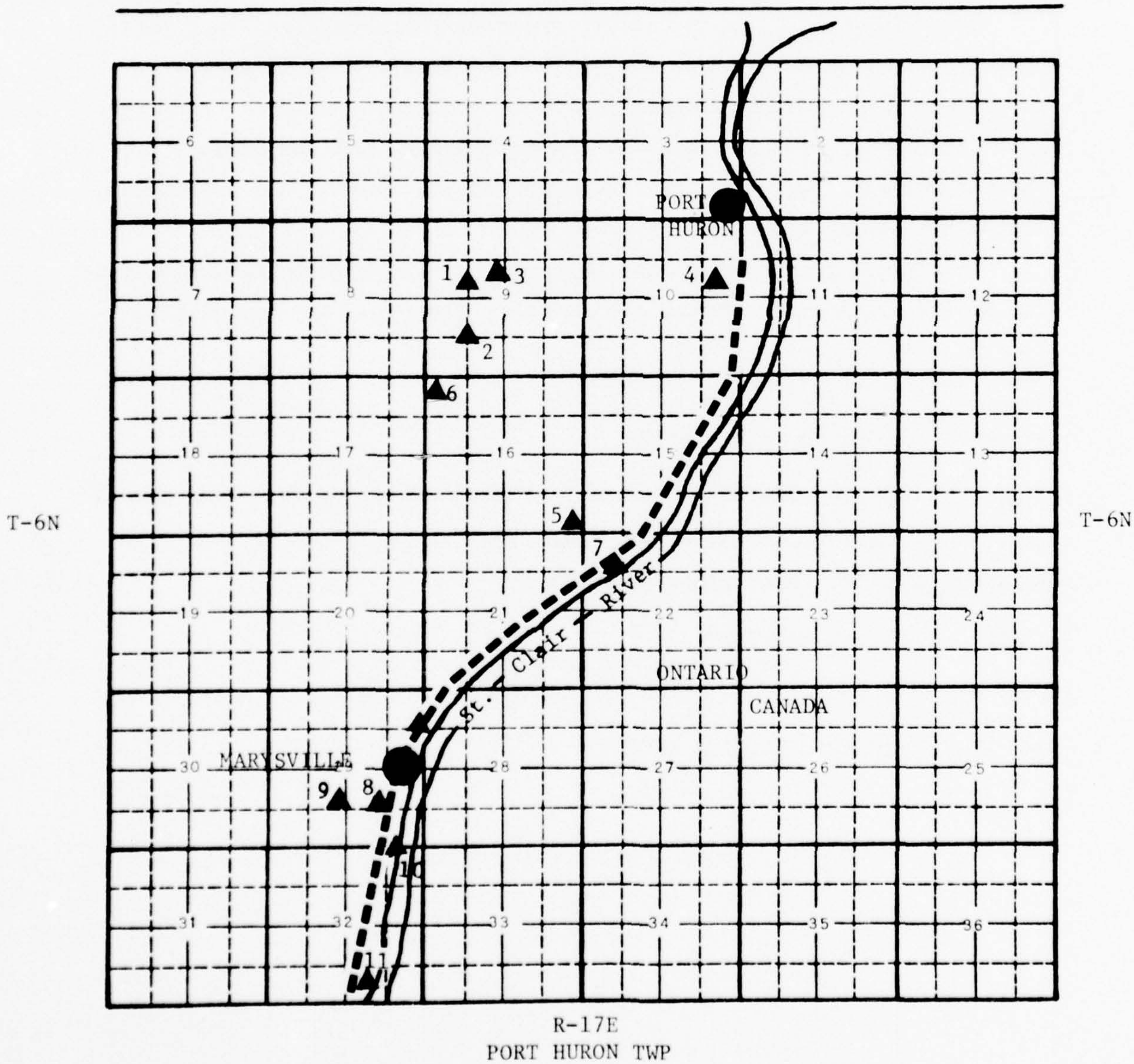


TOWNSHIP SECTION NUMBER

TOWNSHIP 6N **RANGE** 17E **COUNTY** ST. CLAIR **STATE** MICHIGAN

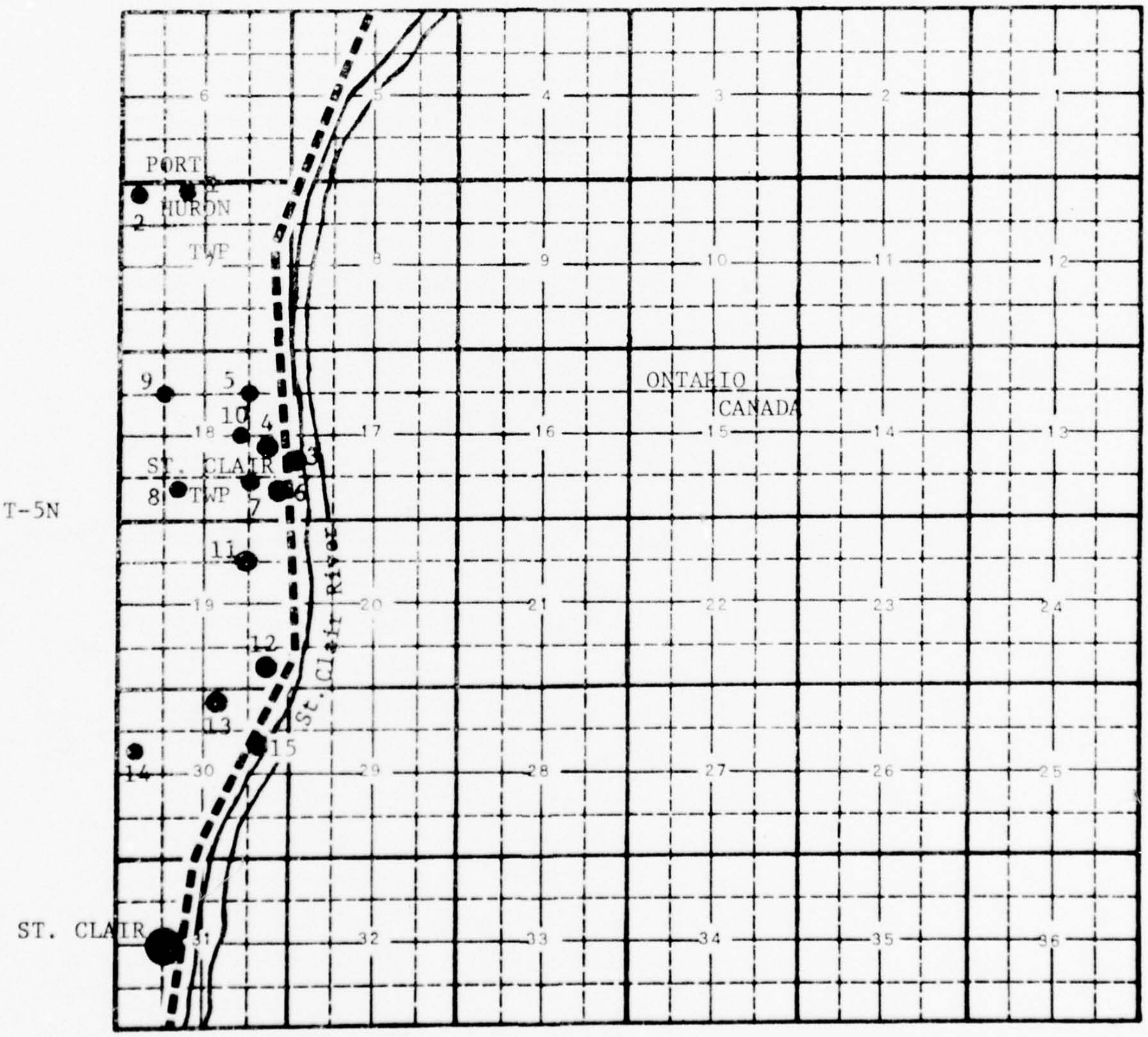
NOTES: PORT HURON TO ALGONAC TUNNEL 1-6

APPROX. LOCATIONS OF OIL & GAS LOGS



TOWNSHIP 5N RANGE 17E COUNTY ST. CLAIR STATE MICHIGAN

NOTES: PORT HURON TO ALGONAC TUNNEL 2-6

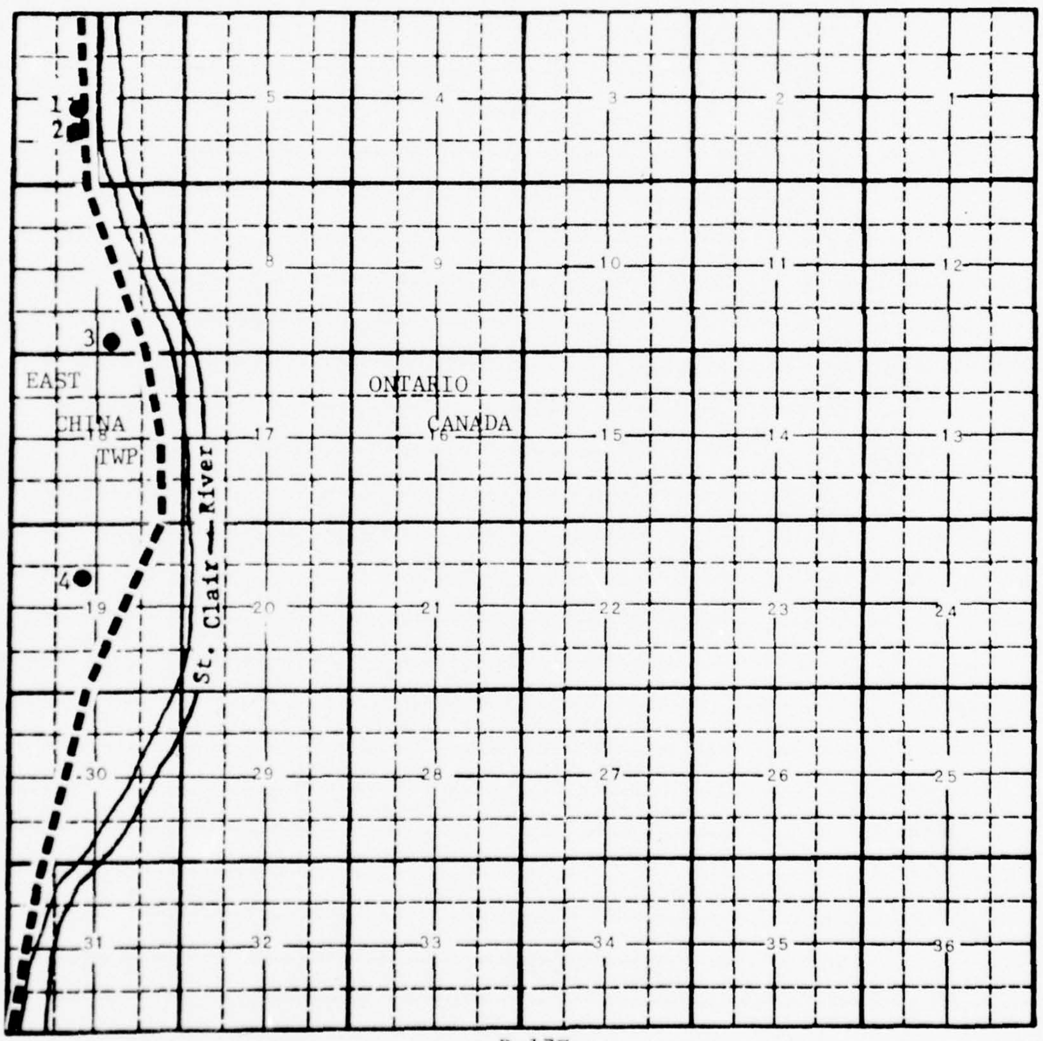
T-5N  T-5N

R-17E

TOWNSHIP 4N **RANGE** 17E **COUNTY** ST. CLAIR **STATE** MICHIGAN

NOTES: PORT HURON TO ALGONAC TUNNEL 3-6

T-4N

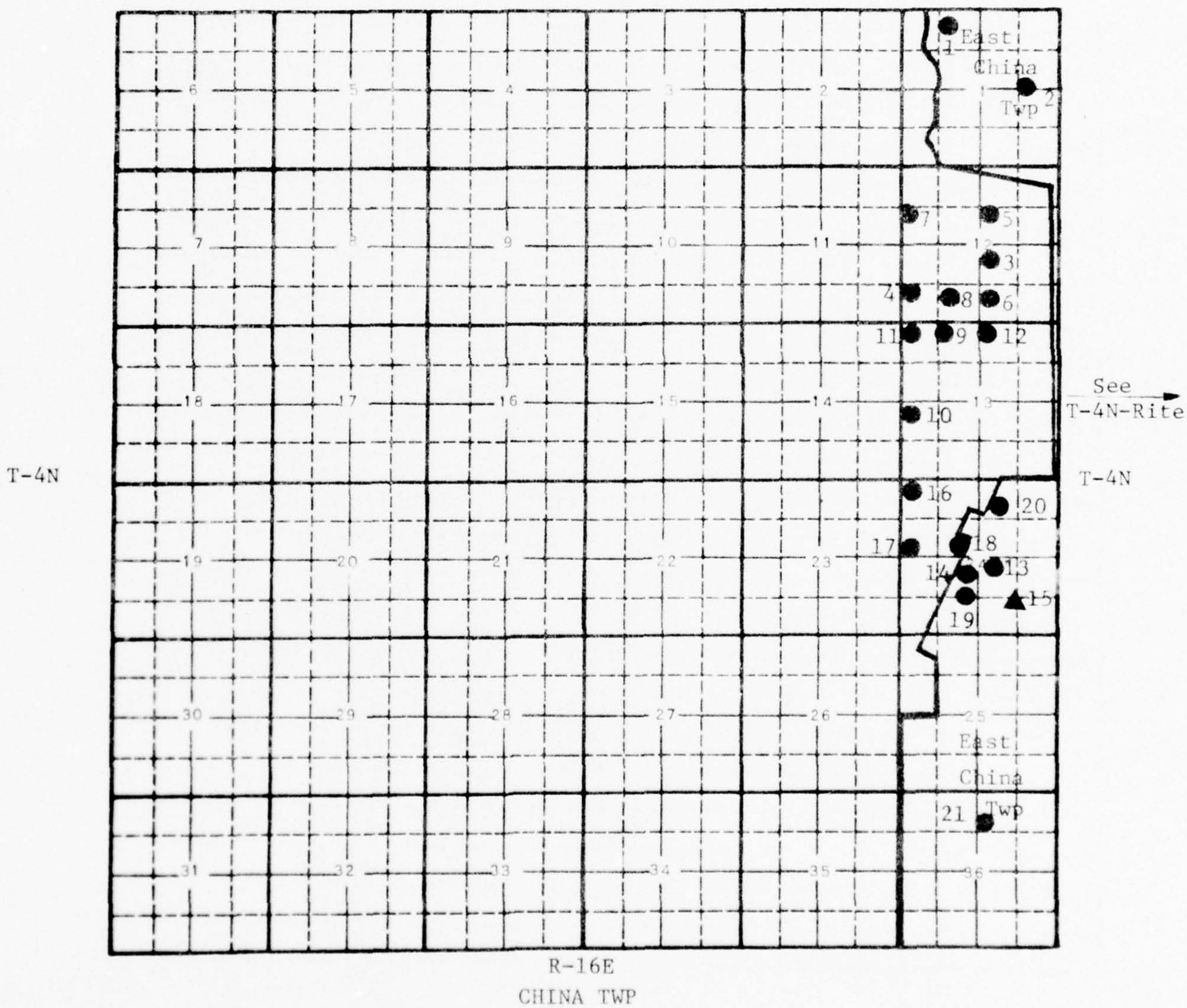


T-4N

R-17E
EAST CHINA TWP

TOWNSHIP 4N **RANGE** 16E **COUNTY** ST. CLAIR **STATE** MICHIGAN

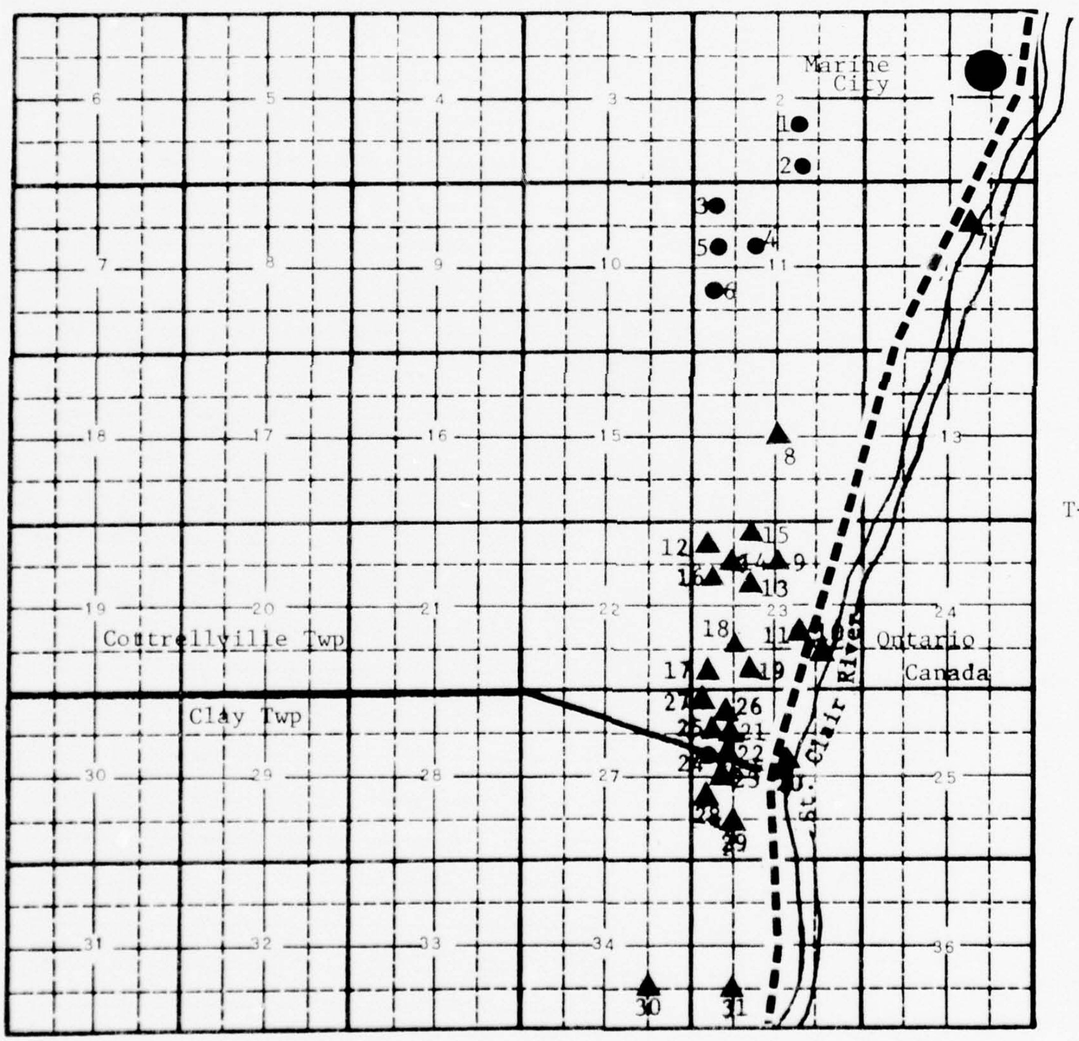
NOTES: PORT HURON TO ALGONAC TUNNEL 4-6



TOWNSHIP 3N **RANGE** 16E **COUNTY** ST. CLAIR **STATE** MICHIGAN

NOTES: PORT HURON TO ALGONAC TUNNEL 5-6

T-3N



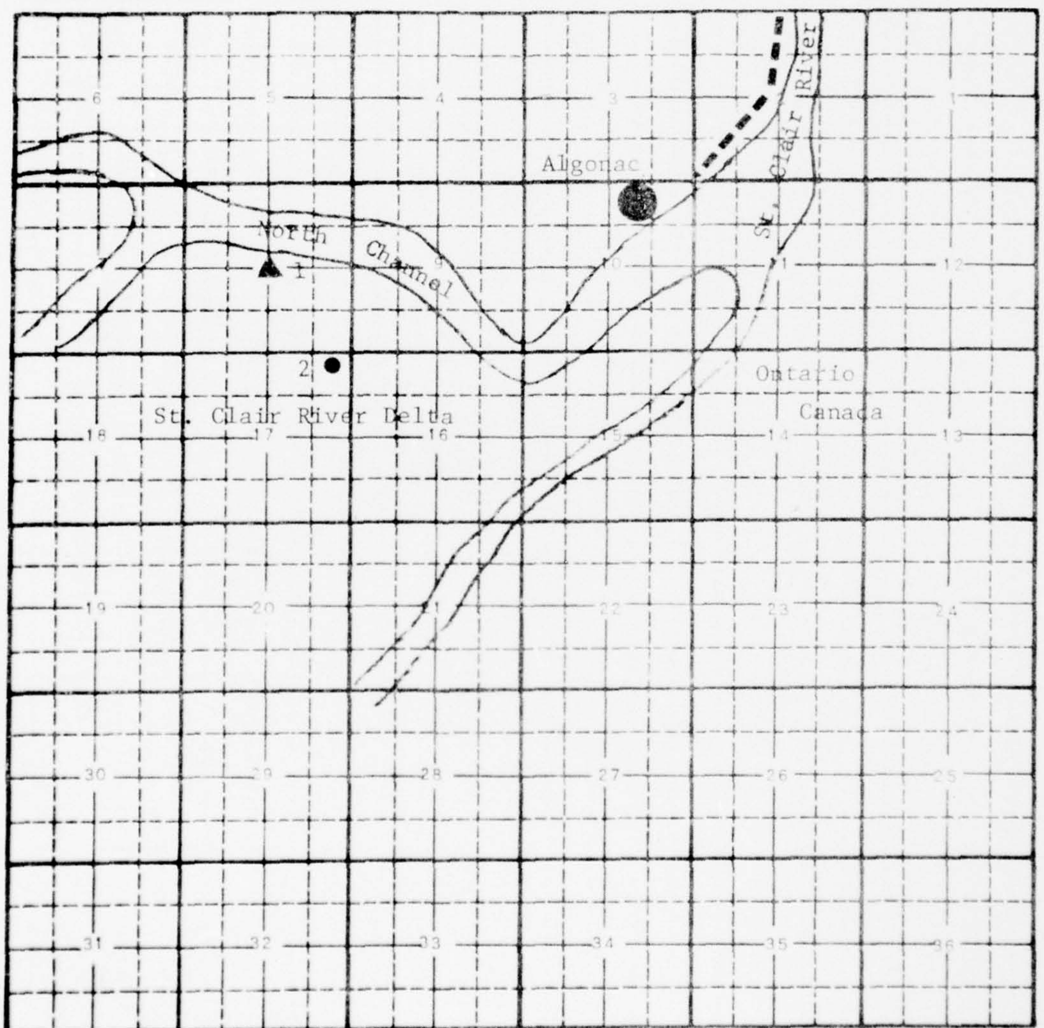
T-3N

R-16E

TOWNSHIP 2N RANGE 16E COUNTY ST. CLAIR STATE MICHIGAN

NOTES: PORT HURON TO ALGONAC TUNNEL 6-6

T-2N



T-2N

R-16E

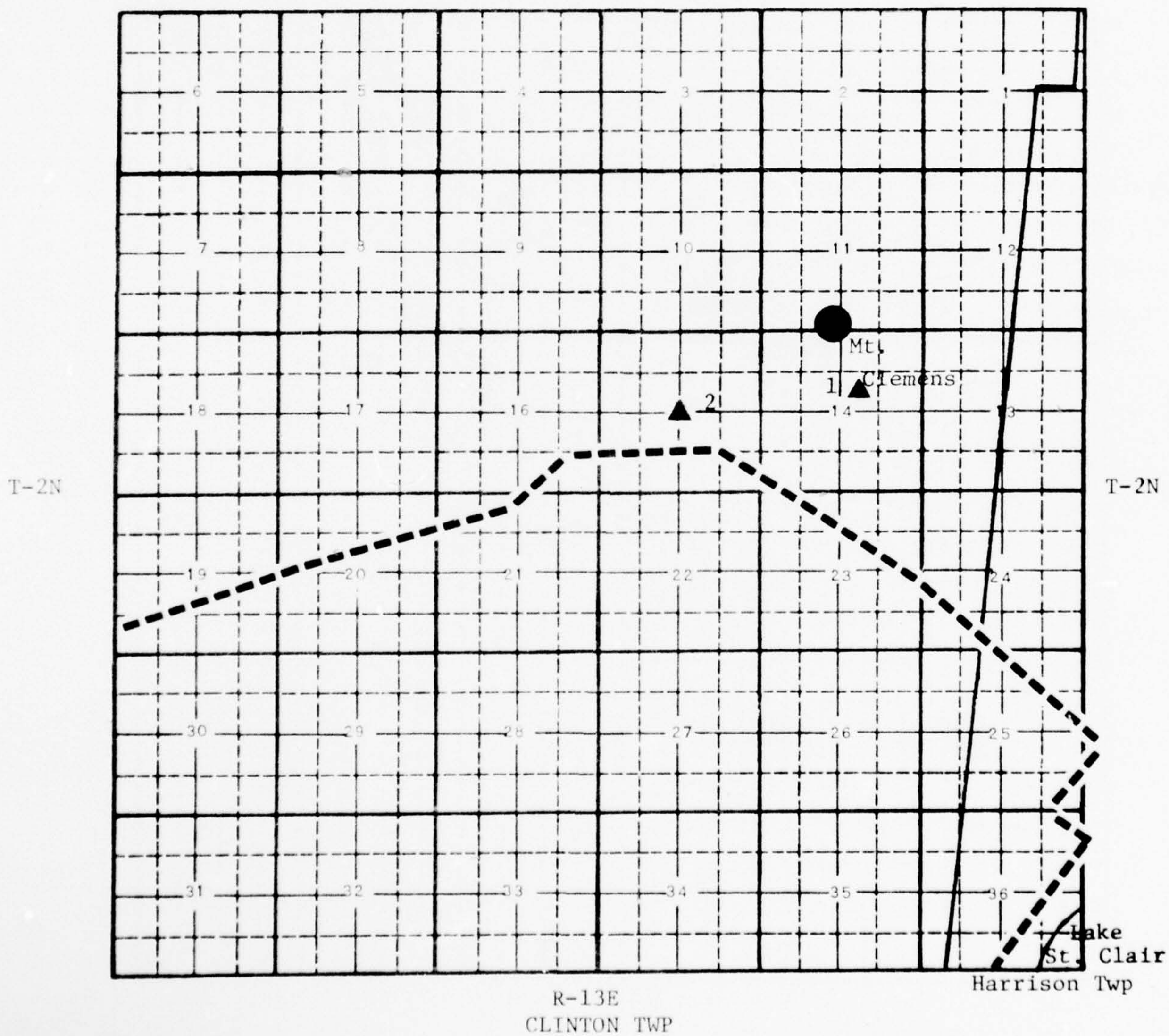
CLAY TWP

TOWNSHIP 2N RANGE 13E COUNTY MACOMB STATE MICHIGAN

NOTES: CLINTON RIVER - JEFFERSON TUNNEL 1-13

FROM MACOMB TO MONROE COUNTIES

APPROX. LOCATIONS OF OIL & GAS RECORDS

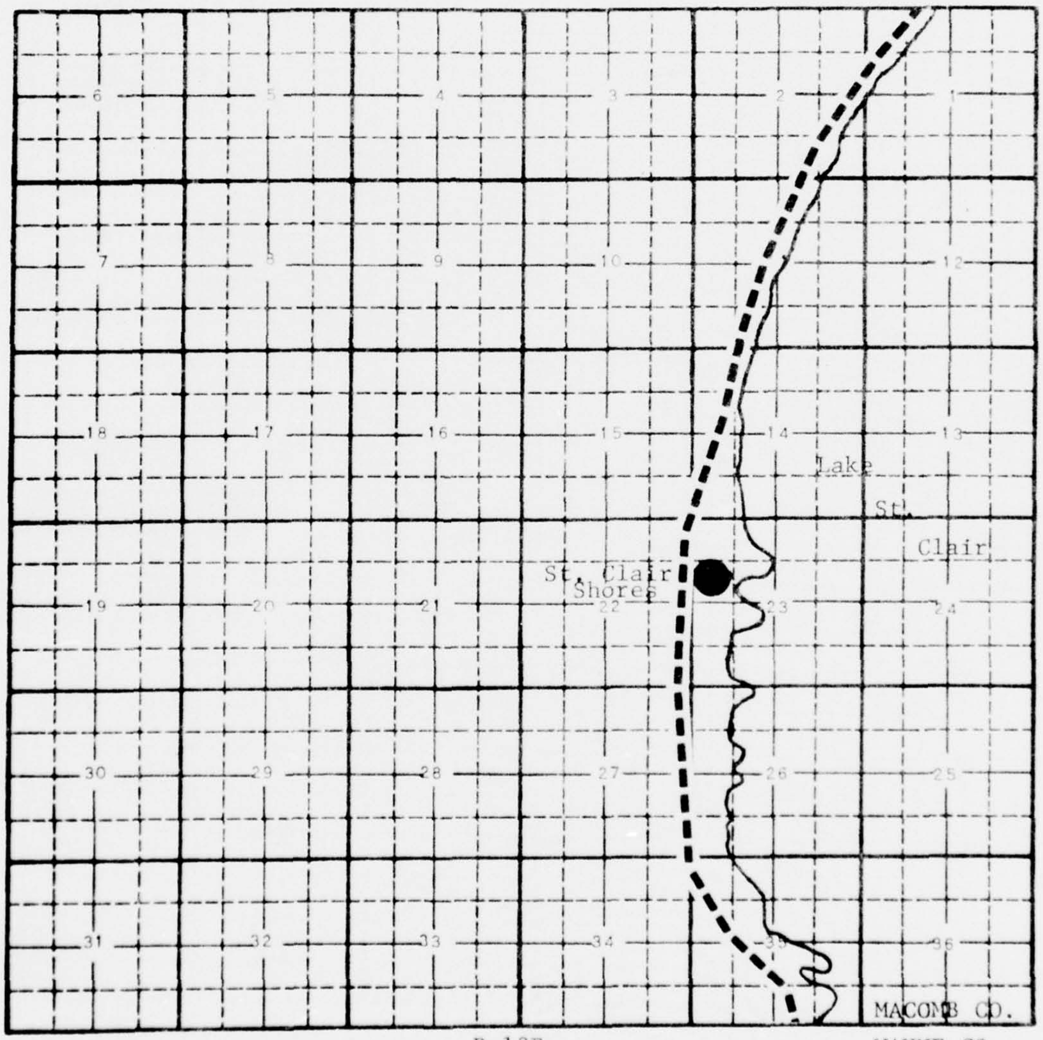


TOWNSHIP 1N **RANGE** 13E **COUNTY** MACOMB **STATE** MICHIGAN

NOTES: CLINTON RIVER - JEFFERSON AVE TUNNEL 2-13

NO OIL & GAS RECORDS NR. OR ALONG ROUTE

T-1N



T-1N

R-13E

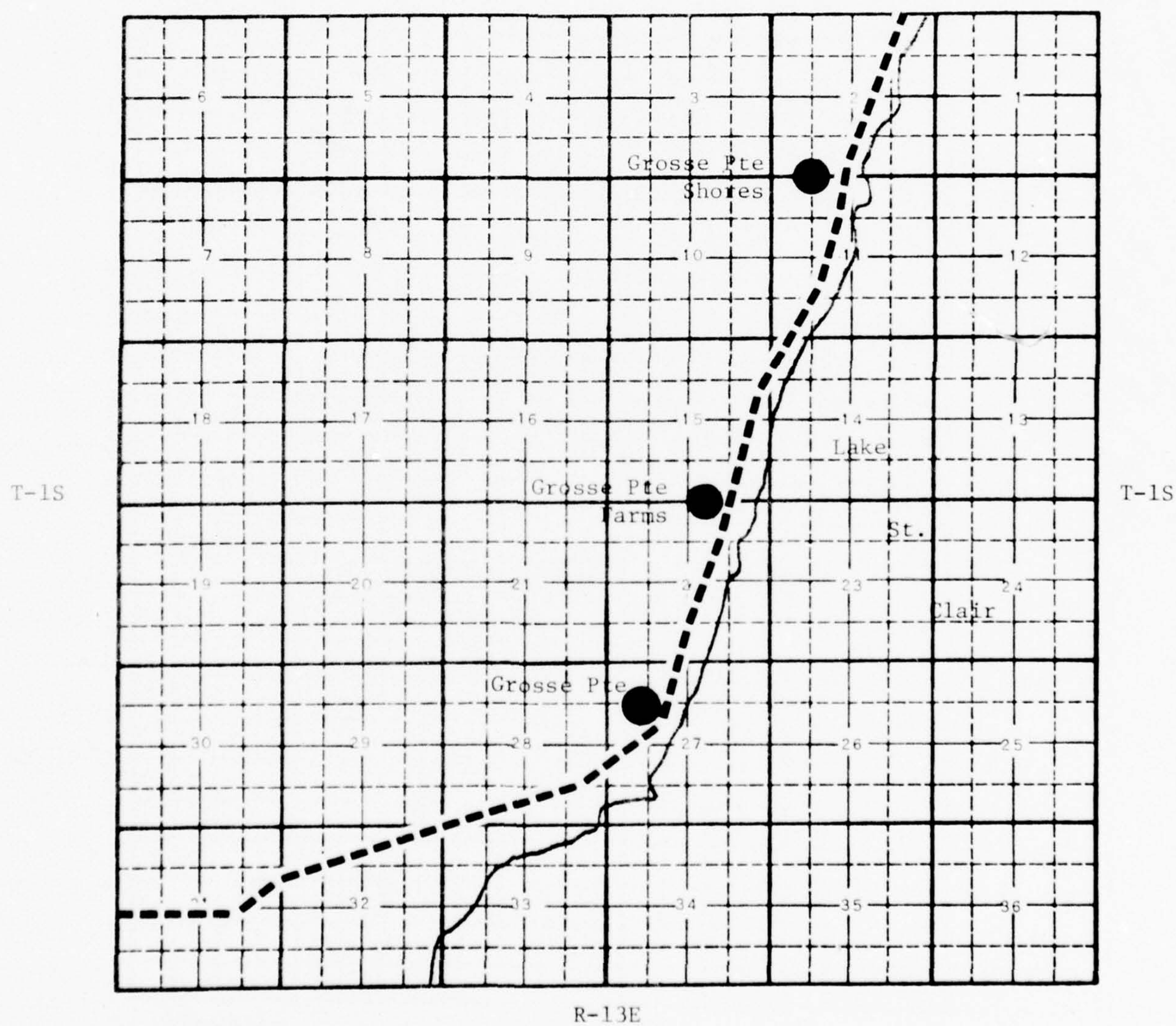
WAYNE CO.

ERIN & LAKE TWPS

TOWNSHIP 1S **RANGE** 13E **COUNTY** WAYNE **STATE** MICHIGAN

NOTES: CLINTON RIVER - JEFFERSON AVE TUNNEL 3-13

NO OIL & GAS LOGS NR OR ALONG ROUTE

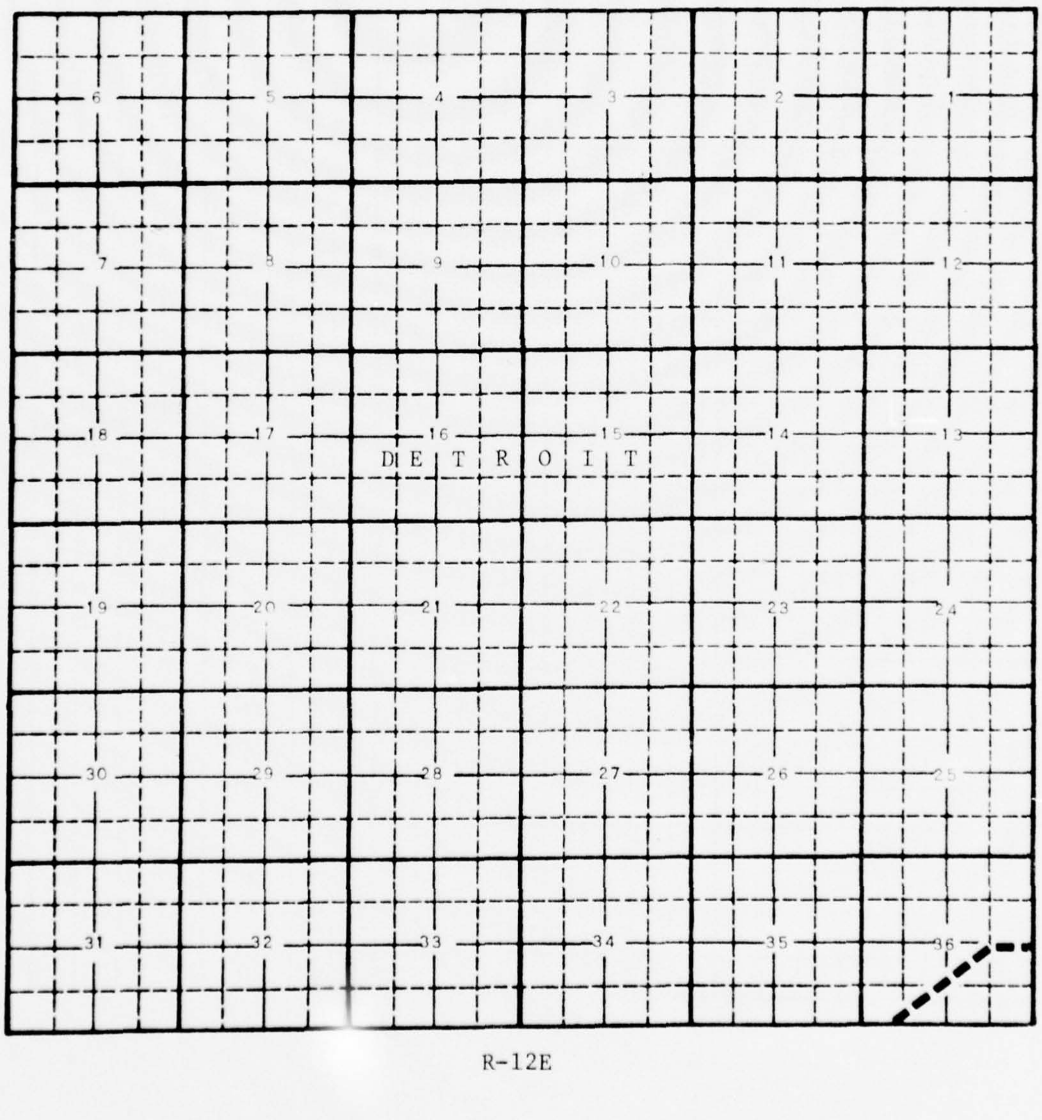


TOWNSHIP 1S **RANGE** 12E **COUNTY** WAYNE **STATE** MICHIGAN

NOTES: CLINTON RIVER - JEFFERSON AVE TUNNEL 4-13

NO OIL & GAS LOGS NR. OR ALONG ROUTE

T-1S



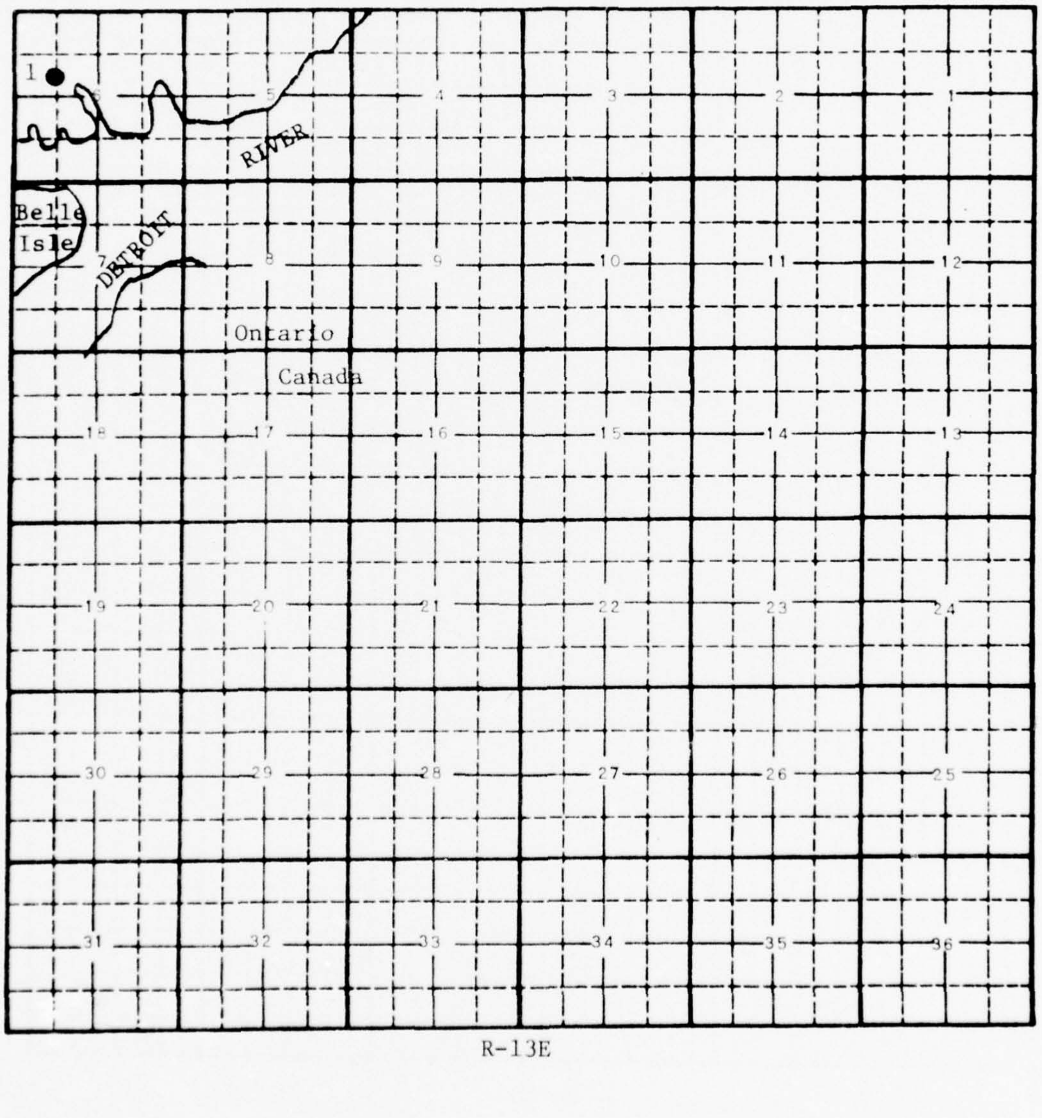
T-1S

R-12E

TOWNSHIP 2S **RANGE** 13E **COUNTY** WAYNE **STATE** MICHIGAN

NOTES: CLINTON RIVER - JEFFERSON AVE TUNNEL 5-13

T-2S

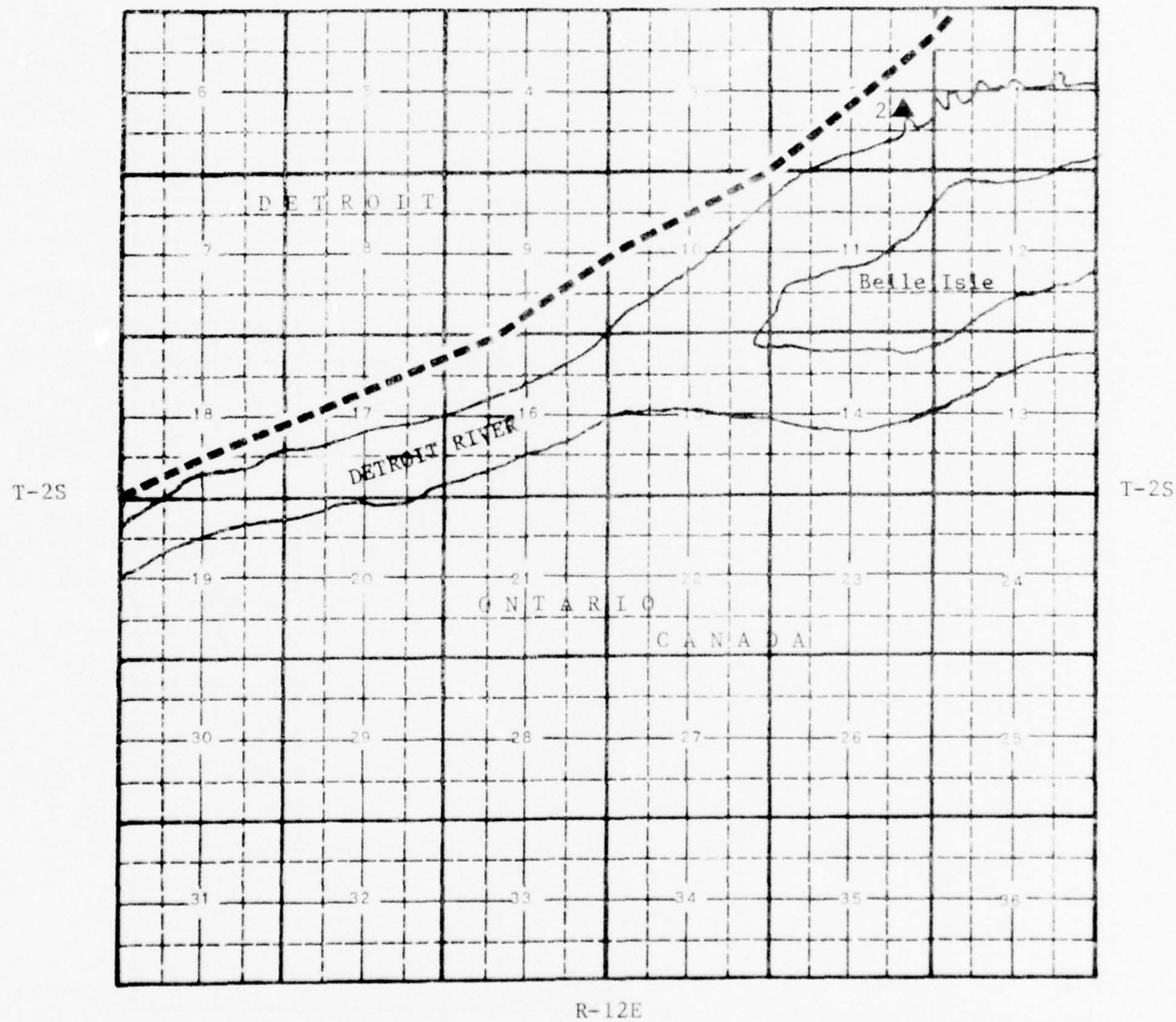


T-2S

R-13E

TOWNSHIP 2S RANGE 12E COUNTY WAYNE STATE MICHIGAN

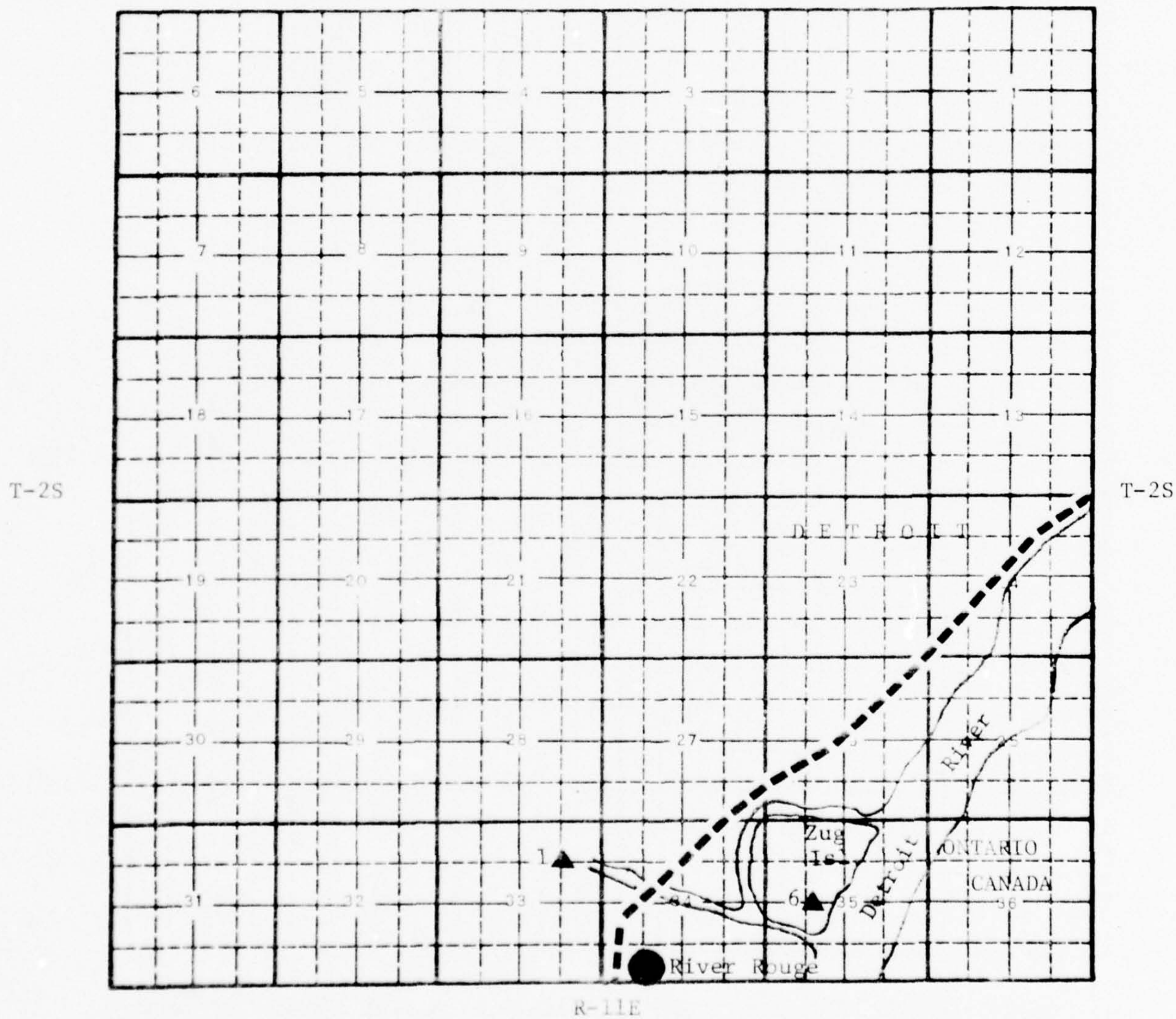
NOTES: CLINTON RIVER - JEFFERSON AVE TUNNEL 6-13



#1 STROH'S BREWERY WELL - AT PLANT, ELIZABETH & GRATIOT AVENUE, DETROIT

TOWNSHIP 2S RANGE 11E COUNTY WAYNE STATE MICHIGAN

NOTES: CLINTON RIVER - JEFFERSON AVE TUNNEL 7-13

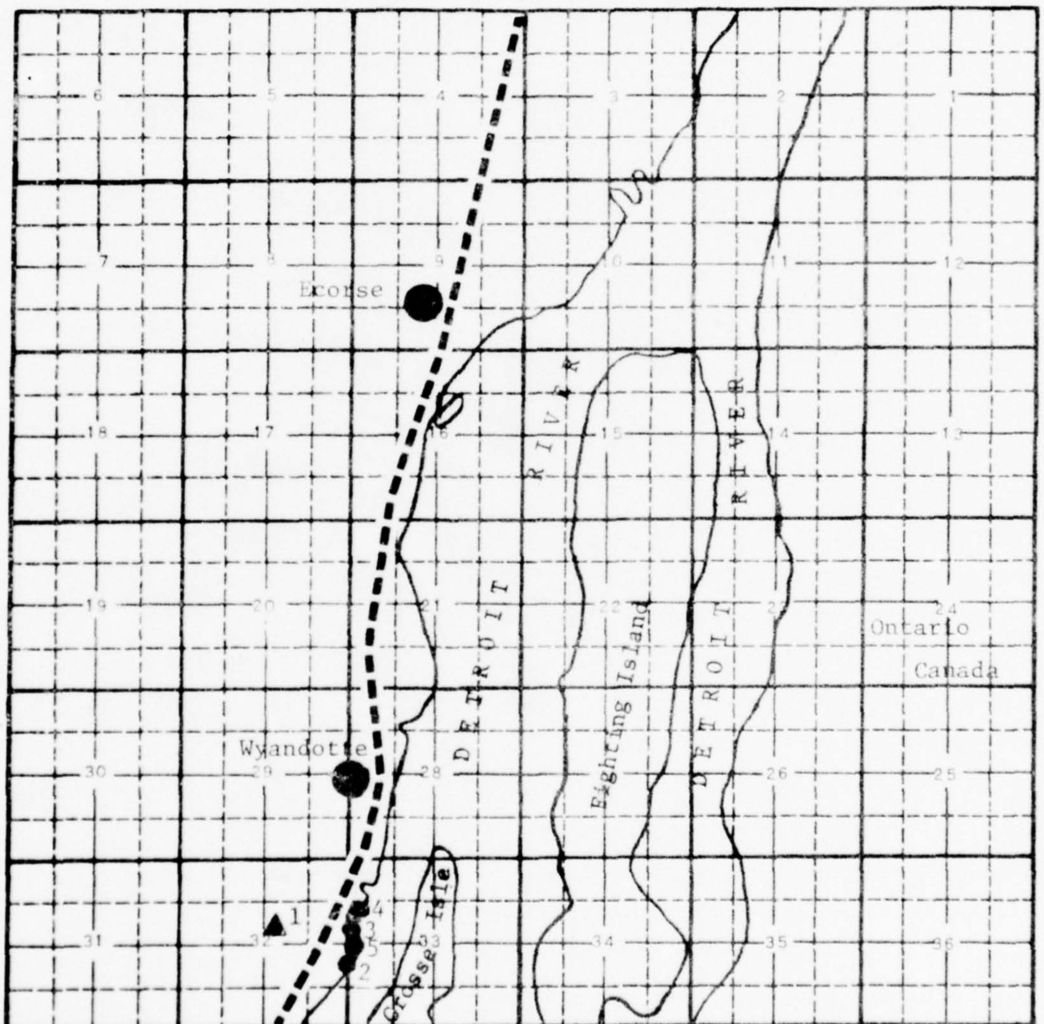


▲ Approx. Locations
Other Records #2 thru #5 Locations very uncertain.

TOWNSHIP 3S RANGE 11E COUNTY WAYNE STATE MICHIGAN

NOTES: CLINTON RIVER - JEFFERSON AVE TUNNEL 8-13

T-3S

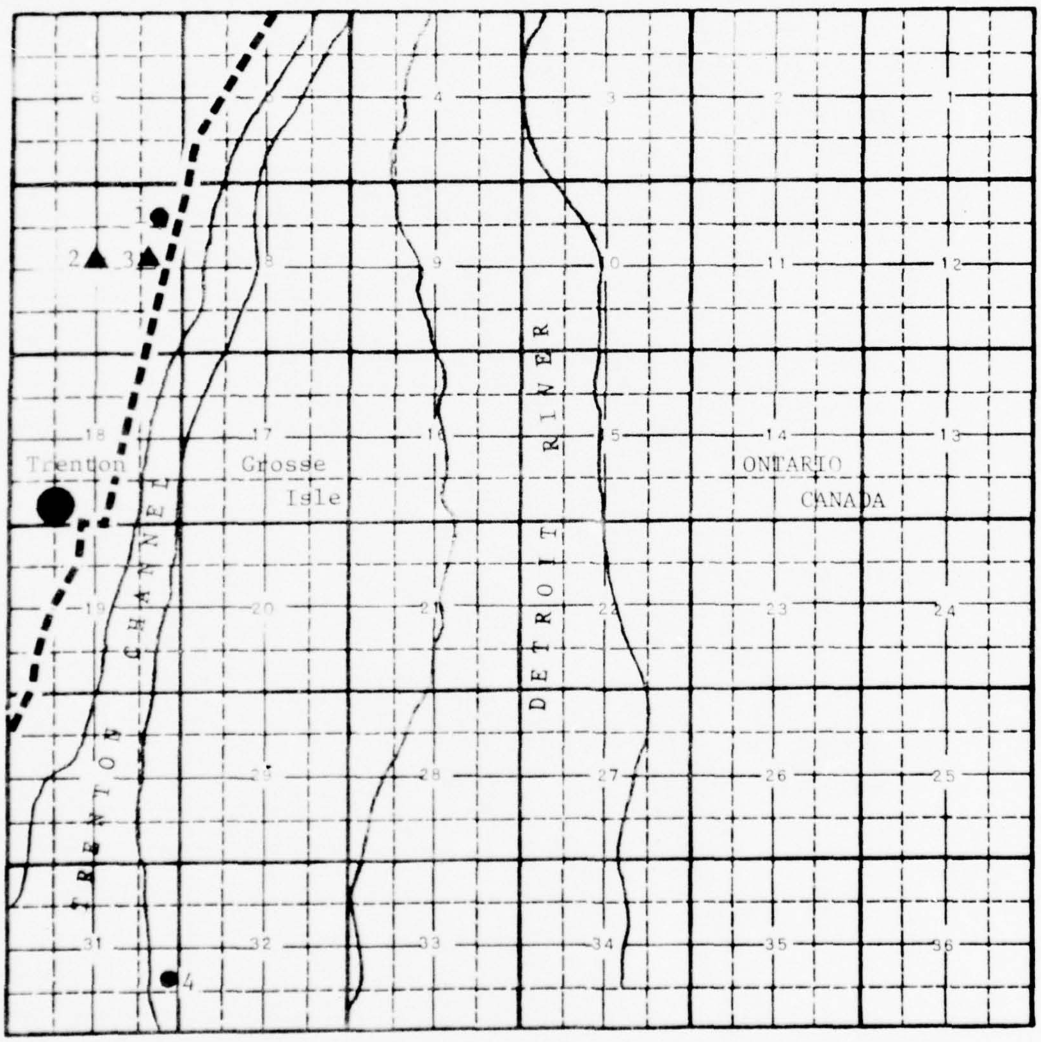


T-3S

R-11E

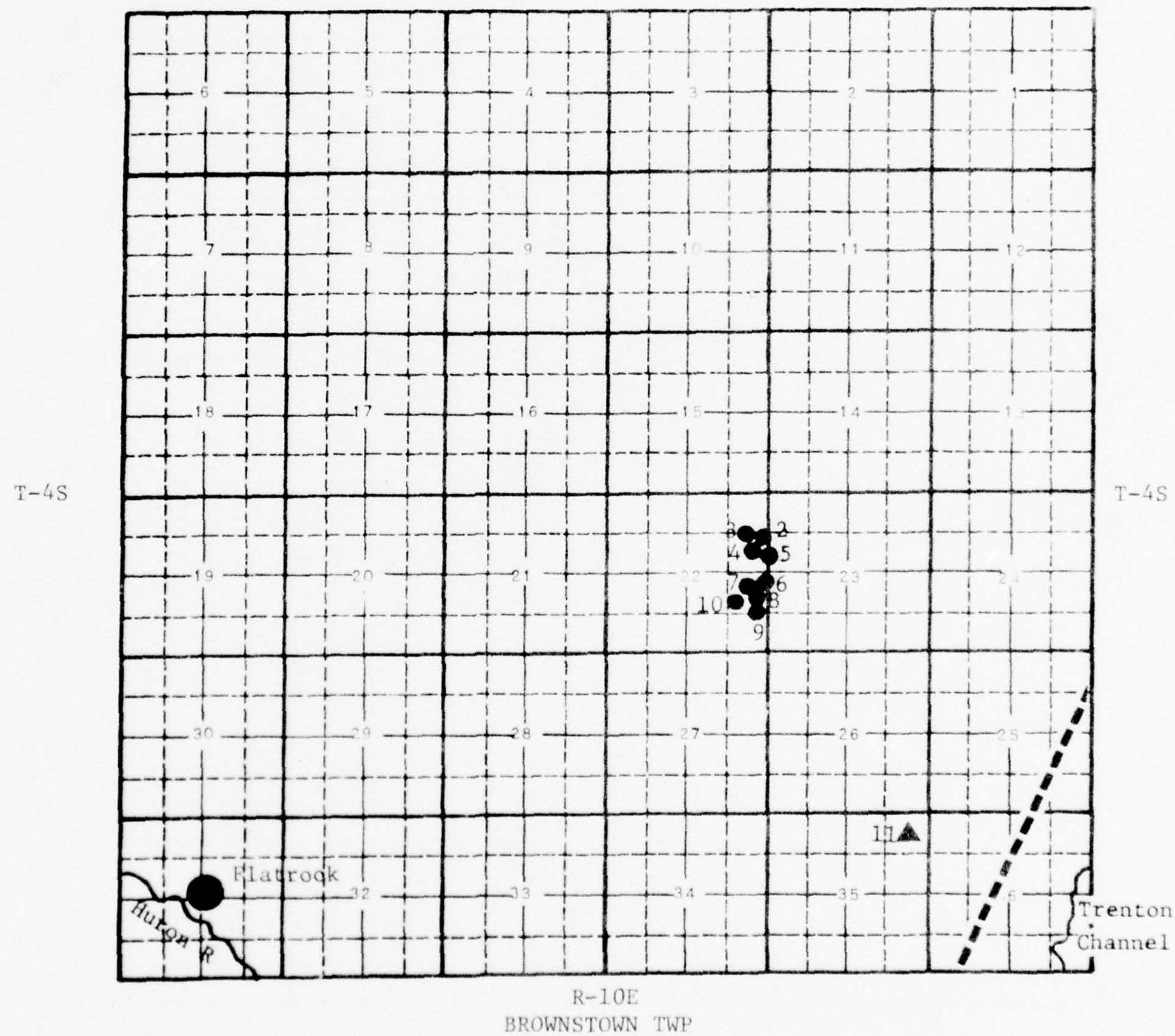
TOWNSHIP 4S RANGE 11E COUNTY WAYNE STATE MICHIGAN

NOTES: CLINTON RIVER - JEFFERSON AVE TUNNEL 9-13



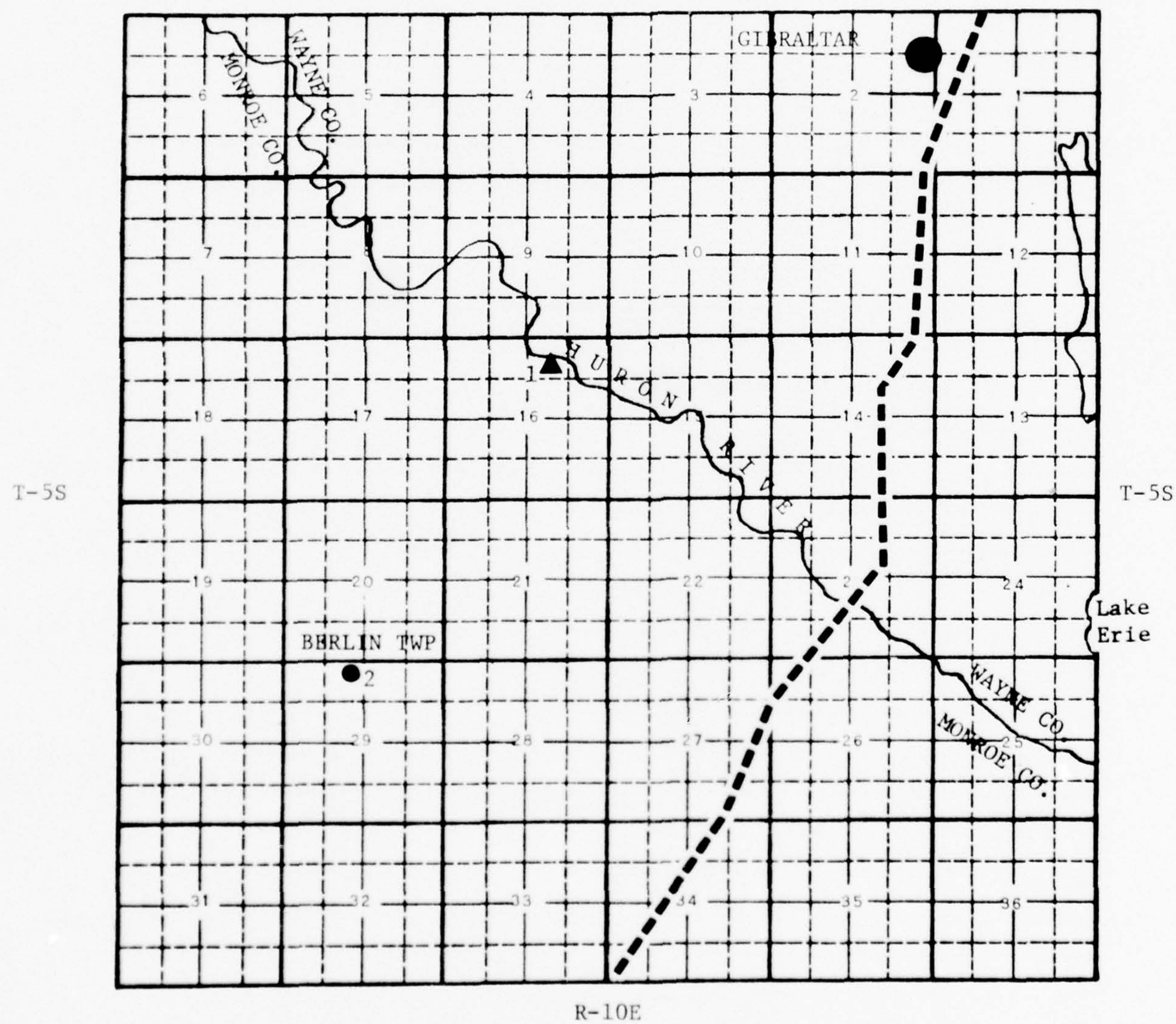
TOWNSHIP 4S RANGE 10E COUNTY WAYNE STATE MICHIGAN

NOTES: CLINTON RIVER - JEFFERSON AVE TUNNEL 10-13



TOWNSHIP 5S **RANGE** 10E **COUNTY** WAYNE/MONROE **STATE** MICHIGAN

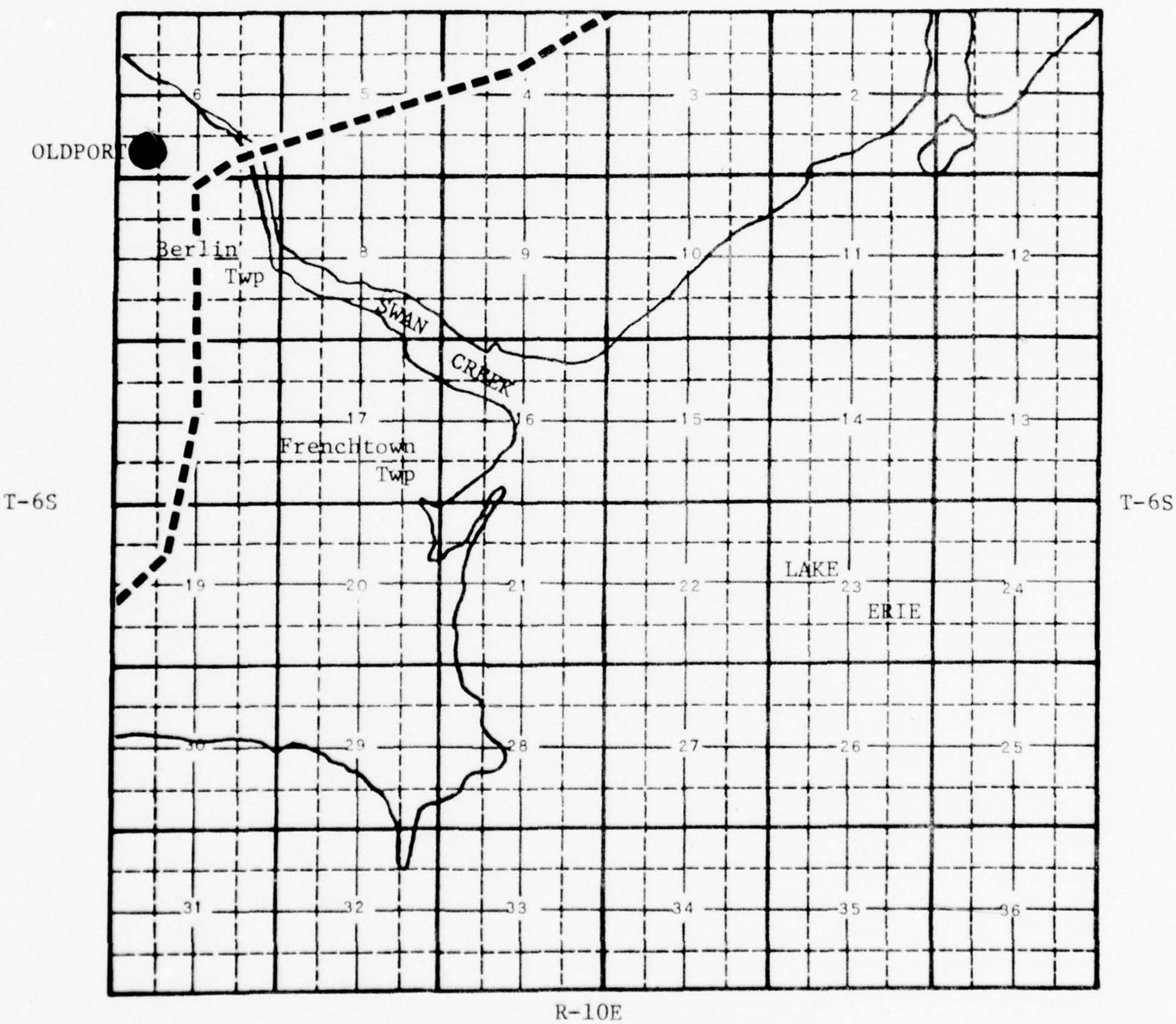
NOTES: CLINTON RIVER - JEFFERSON AVE TUNNEL 11-13



TOWNSHIP T-6S **RANGE** 10E **COUNTY** MONROE **STATE** MICHIGAN

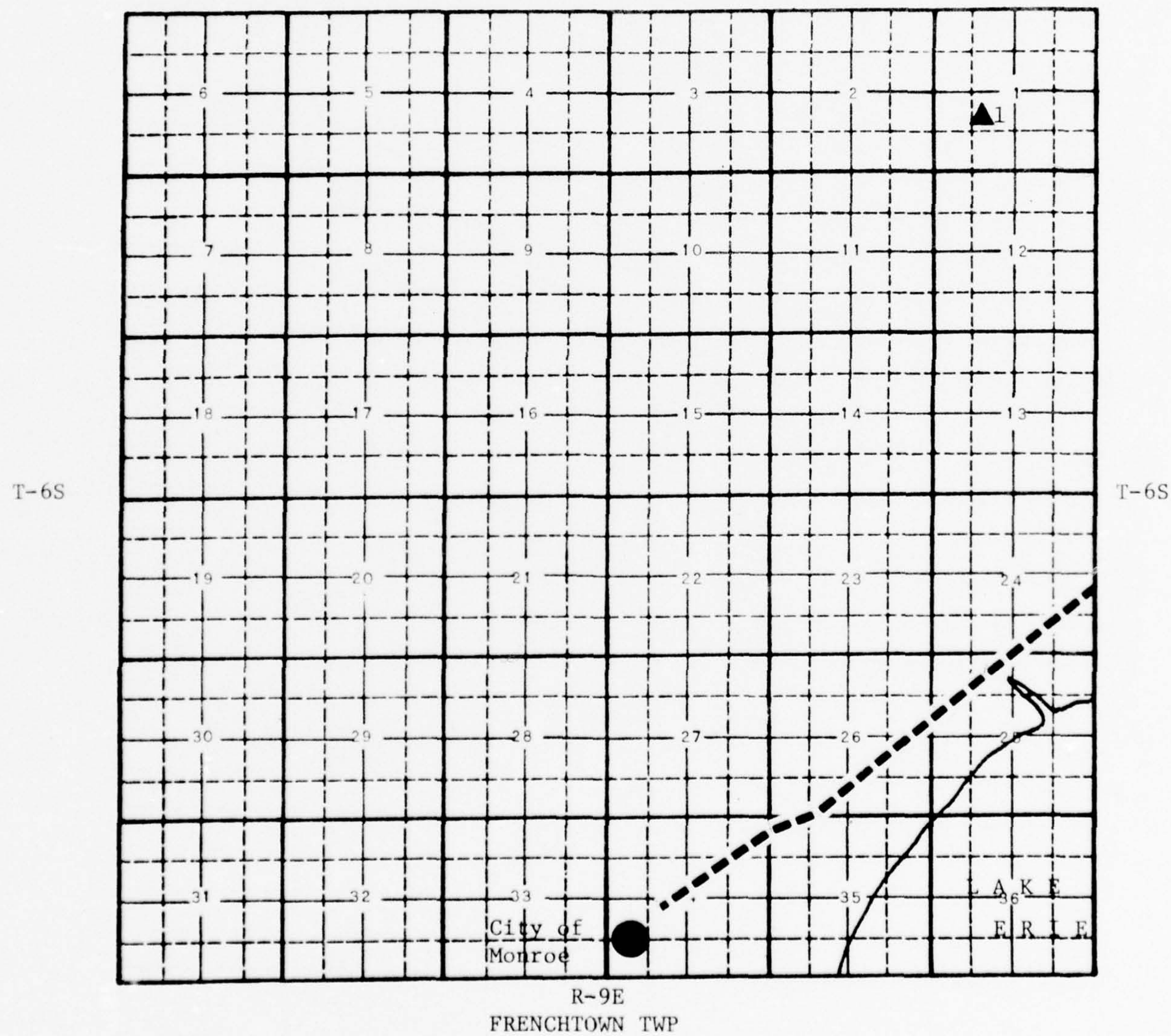
NOTES: CLINTON RIVER - JEFFERSON AVE TUNNEL 12-13

NO OIL & GAS LOGS NR. OR ALONG ROUTE



TOWNSHIP 6S **RANGE** 9E **COUNTY** MONROE **STATE** MICHIGAN

NOTES: CLINTON RIVER - JEFFERSON AVE TUNNEL 13-13

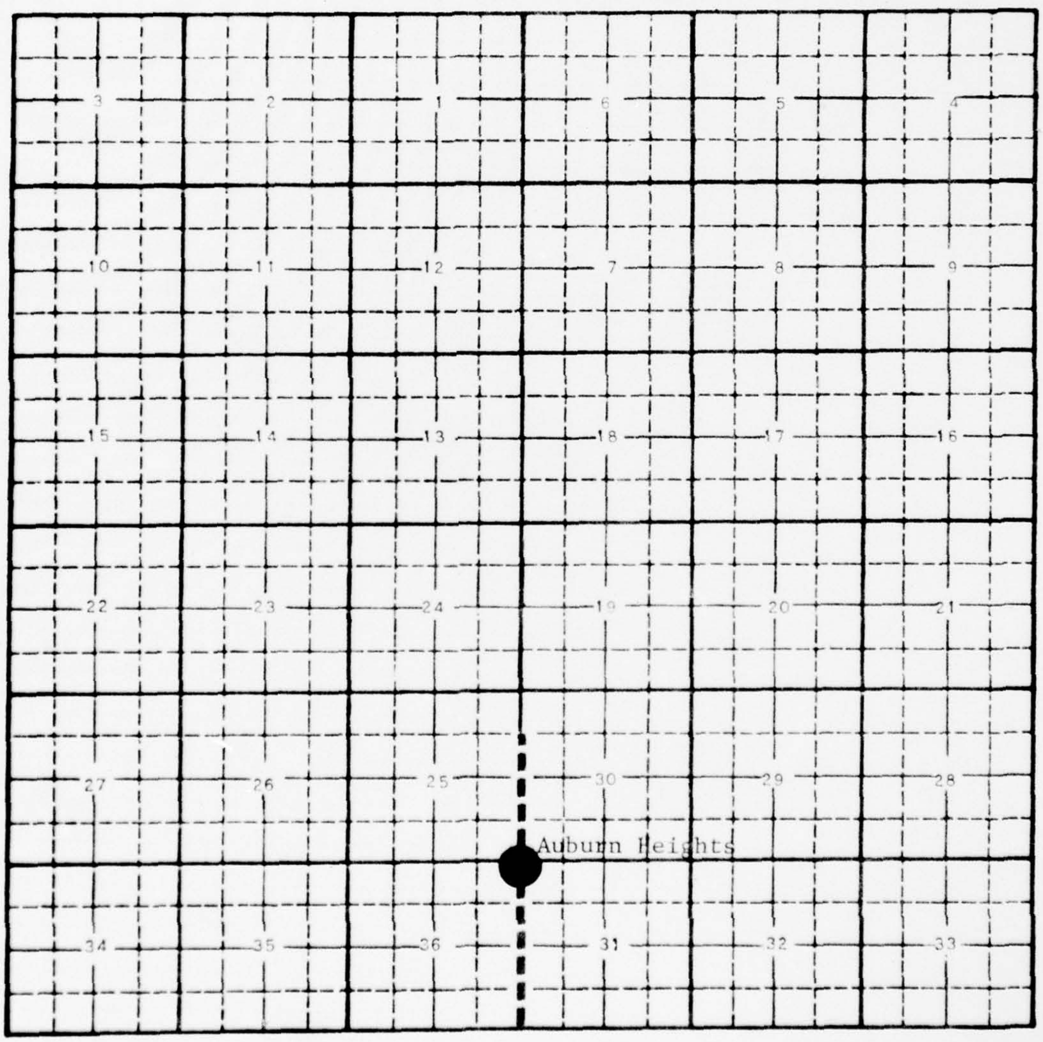


TOWNSHIP 3N **RANGE** 10-11E **COUNTY** OAKLAND **STATE** MICHIGAN

NOTES: UPPER ROUGE RIVER - TELEGRAPH RD. TUNNEL 1-8

NO OIL & GAS LOGS NR. OR ALONG ROUTE

T-3N



T-3N

R-10E
PONTIAC TWP

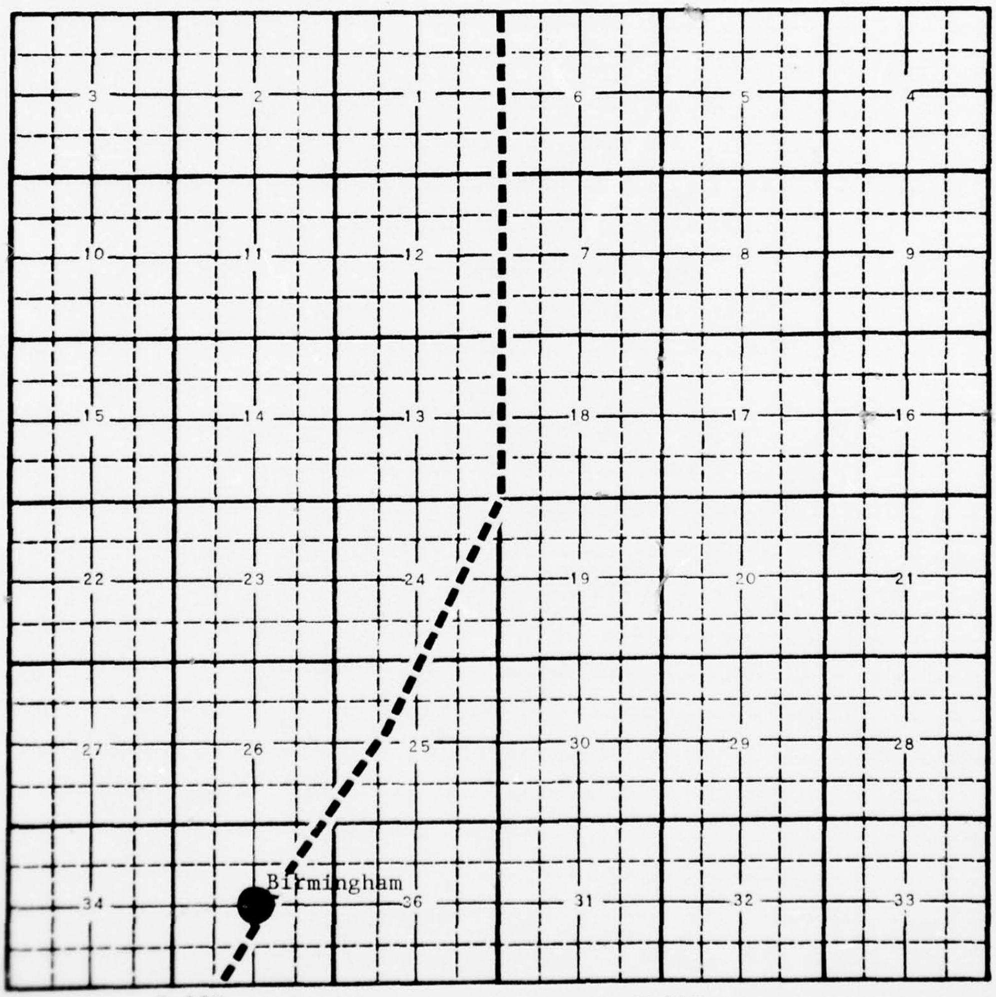
R-11E
AVON TWP

TOWNSHIP 2N **RANGE** 10-11E **COUNTY** OAKLAND **STATE** MICHIGAN

NOTES: UPPER ROUGE RIVER - TELEGRAPH RD. TUNNEL 2-8

NO OIL & GAS LOGS NR. OR ALONG ROUTE

T-2N



T-2N

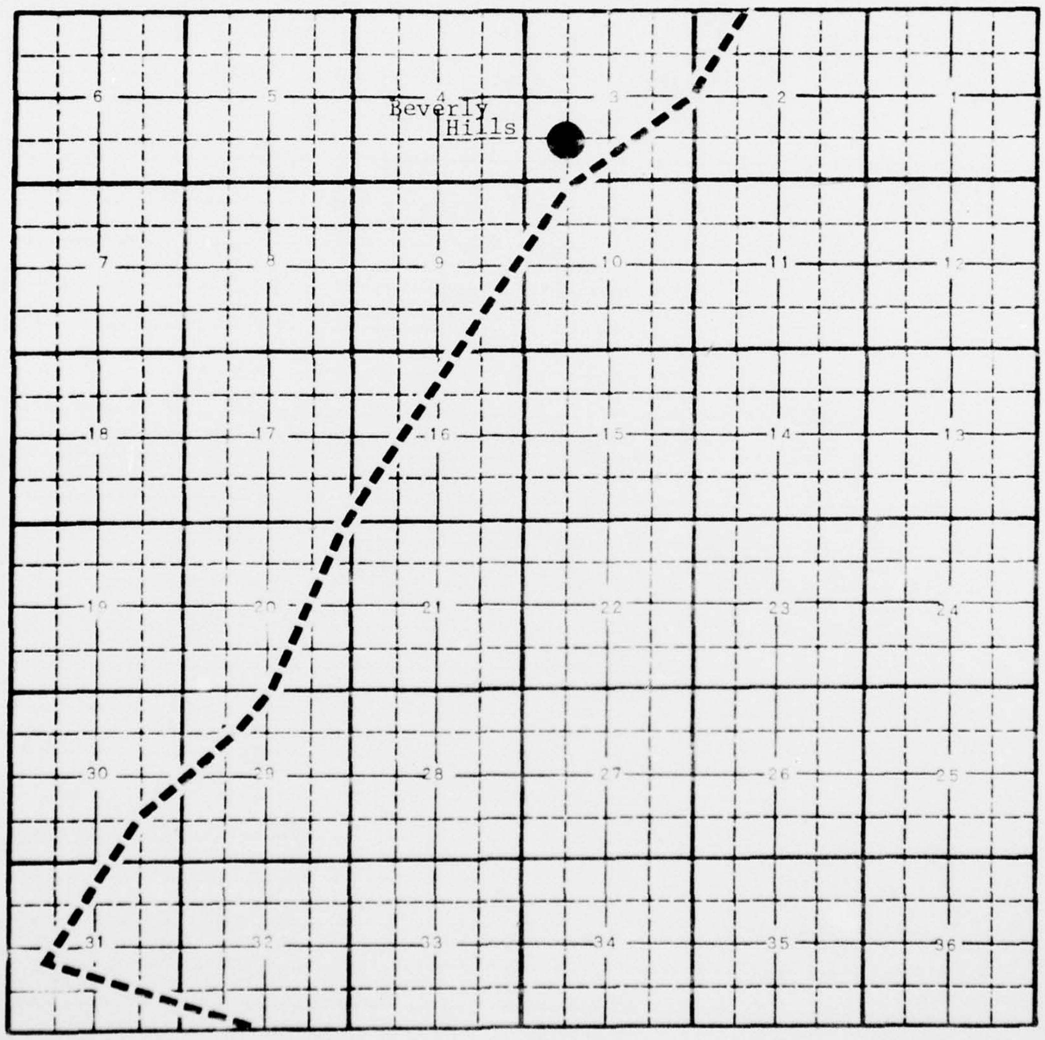
R-10E
BLOOMFIELD TWP

R-11E
TROY TWP

TOWNSHIP 1N **RANGE** 10E **COUNTY** OAKLAND **STATE** MICHIGAN

NOTES: UPPER ROUGE RIVER - TELEGRAPH RD. TUNNEL 3-8

NO OIL & GAS LOGS NR OR ALONG ROUTE



T-1N

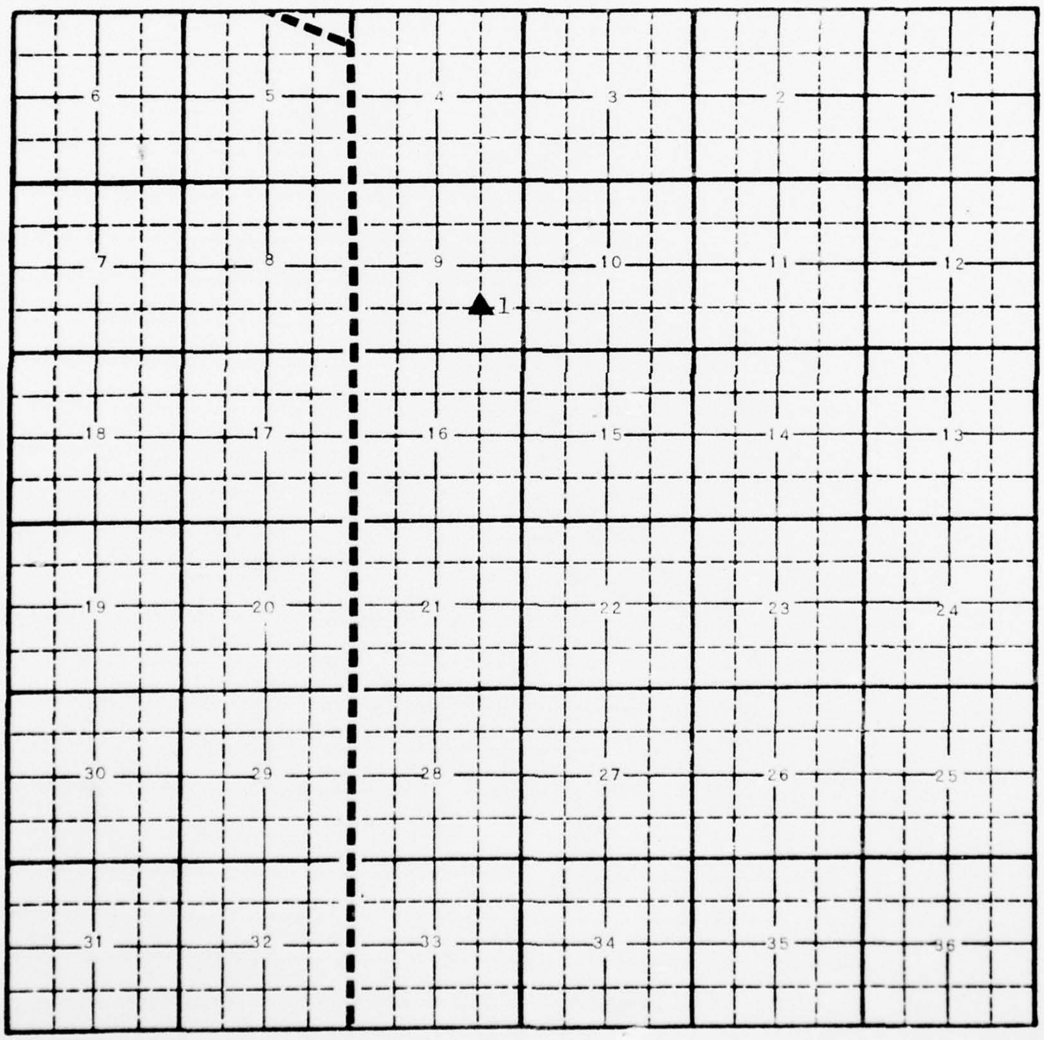
T-1N

R-10E
SOUTHFIELD TWP

TOWNSHIP 1S **RANGE** 10E **COUNTY** WAYNE **STATE** MICHIGAN

NOTES: UPPER ROUGE RIVER - TELEGRAPH RD. TUNNEL 4-8

T-1S



T-1S

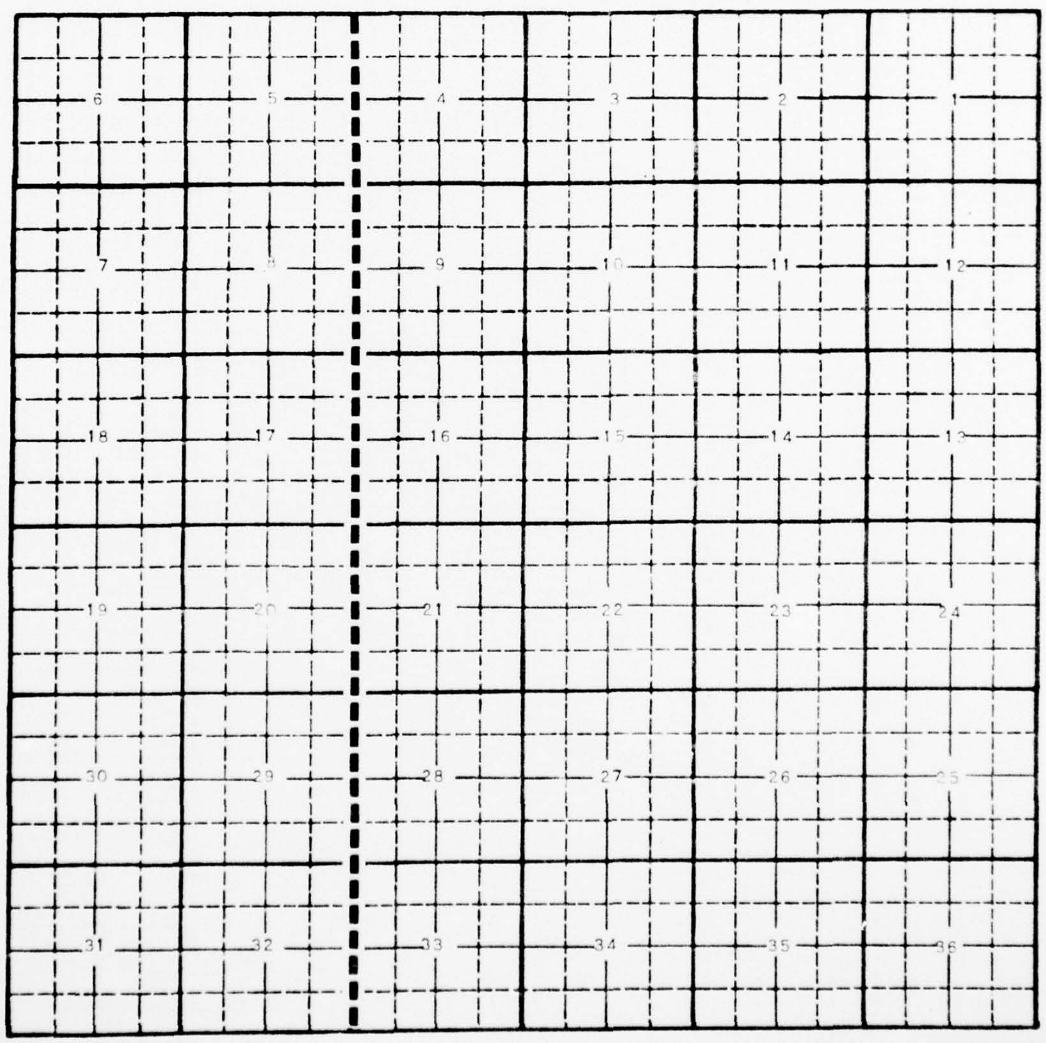
R-10E
REDFORD TWP

TOWNSHIP 2S **RANGE** 10E **COUNTY** WAYNE **STATE** MICHIGAN

NOTES: UPPER ROUGE RIVER - TELEGRAPH RD. TUNNEL 5-8

NO OIL & GAS LOGS NR. OR ALONG ROUTE

T-2S



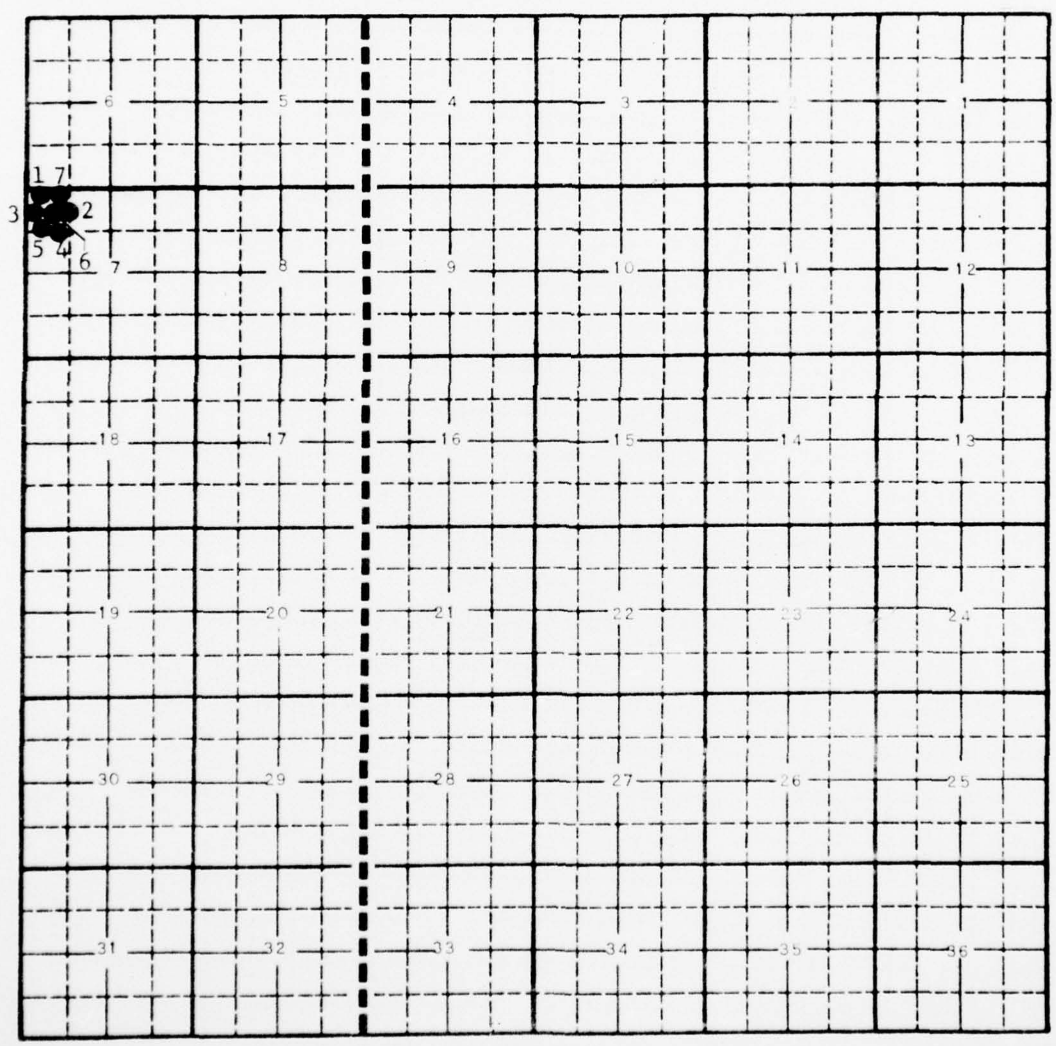
T-2S

R-10E
DEARBORN TWP

TOWNSHIP 3S **RANGE** 10E **COUNTY** WAYNE **STATE** MICHIGAN

NOTES: UPPER ROUGE RIVER - TELEGRAPH RD. TUNNEL 6-8

T-3S

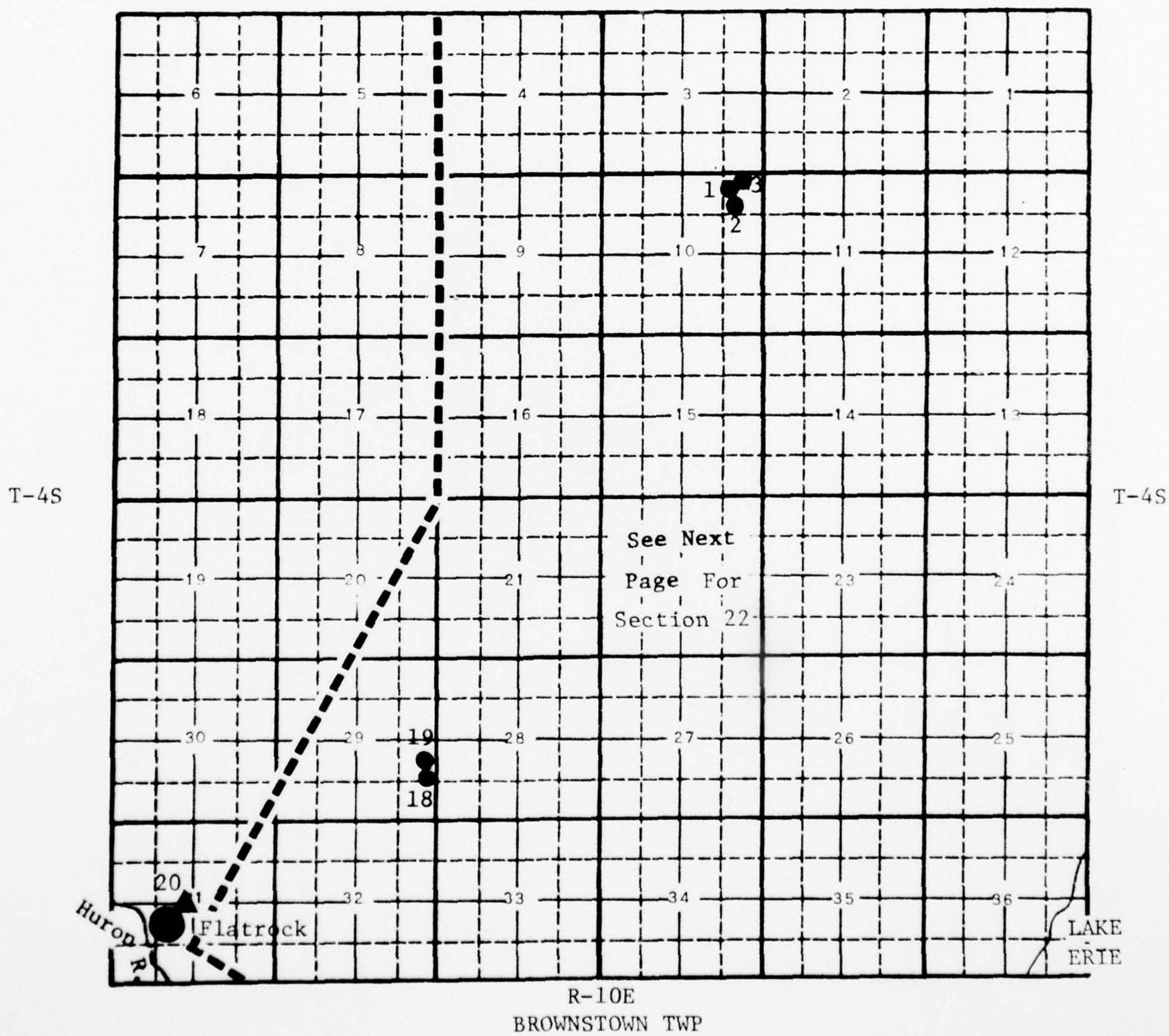


T-3S

R-10E
TAYLOR TWP

TOWNSHIP 4S **RANGE** 10E **COUNTY** WAYNE **STATE** MICHIGAN

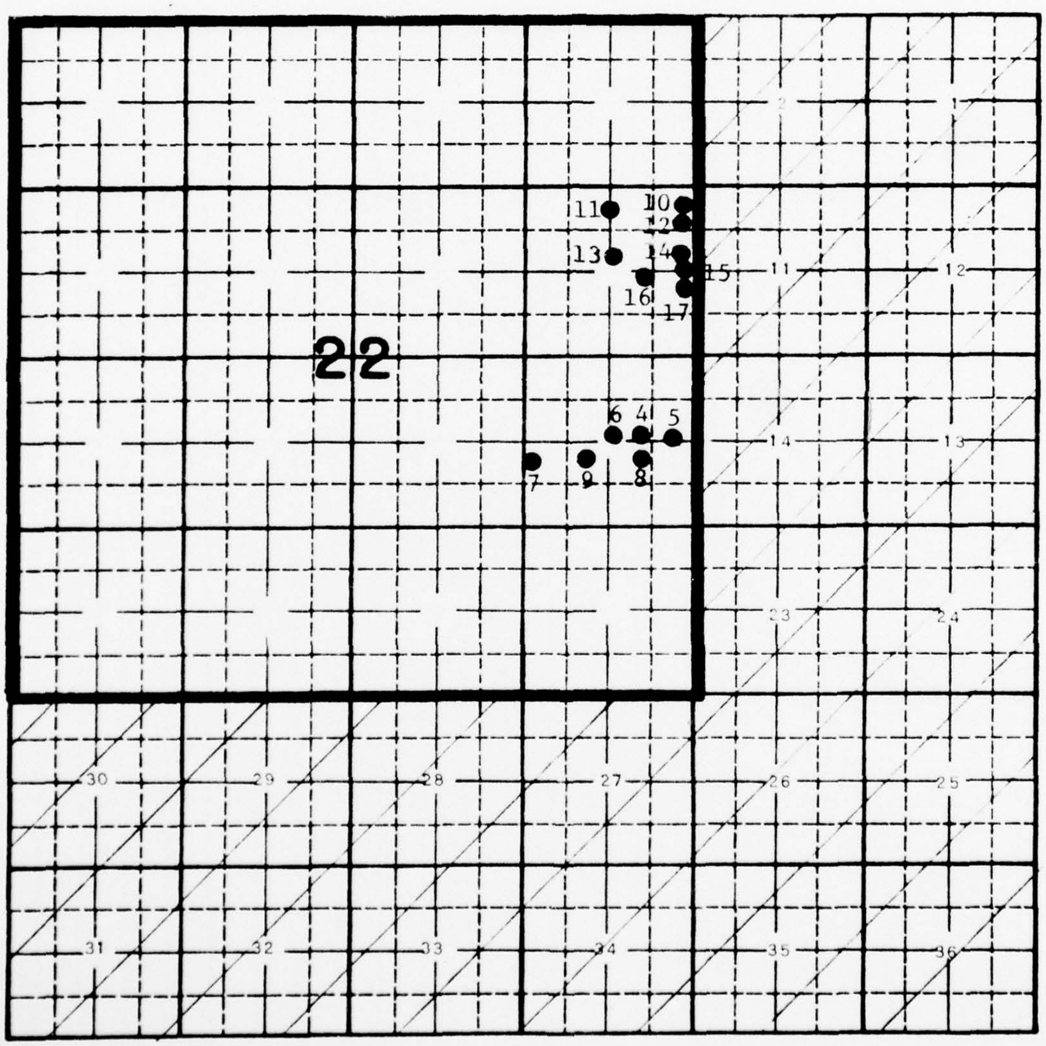
NOTES: UPPER ROUGE RIVER - TELEGRAPH RD. TUNNEL 7-8



TOWNSHIP______ **RANGE**______ **COUNTY**________________ **STATE**________________

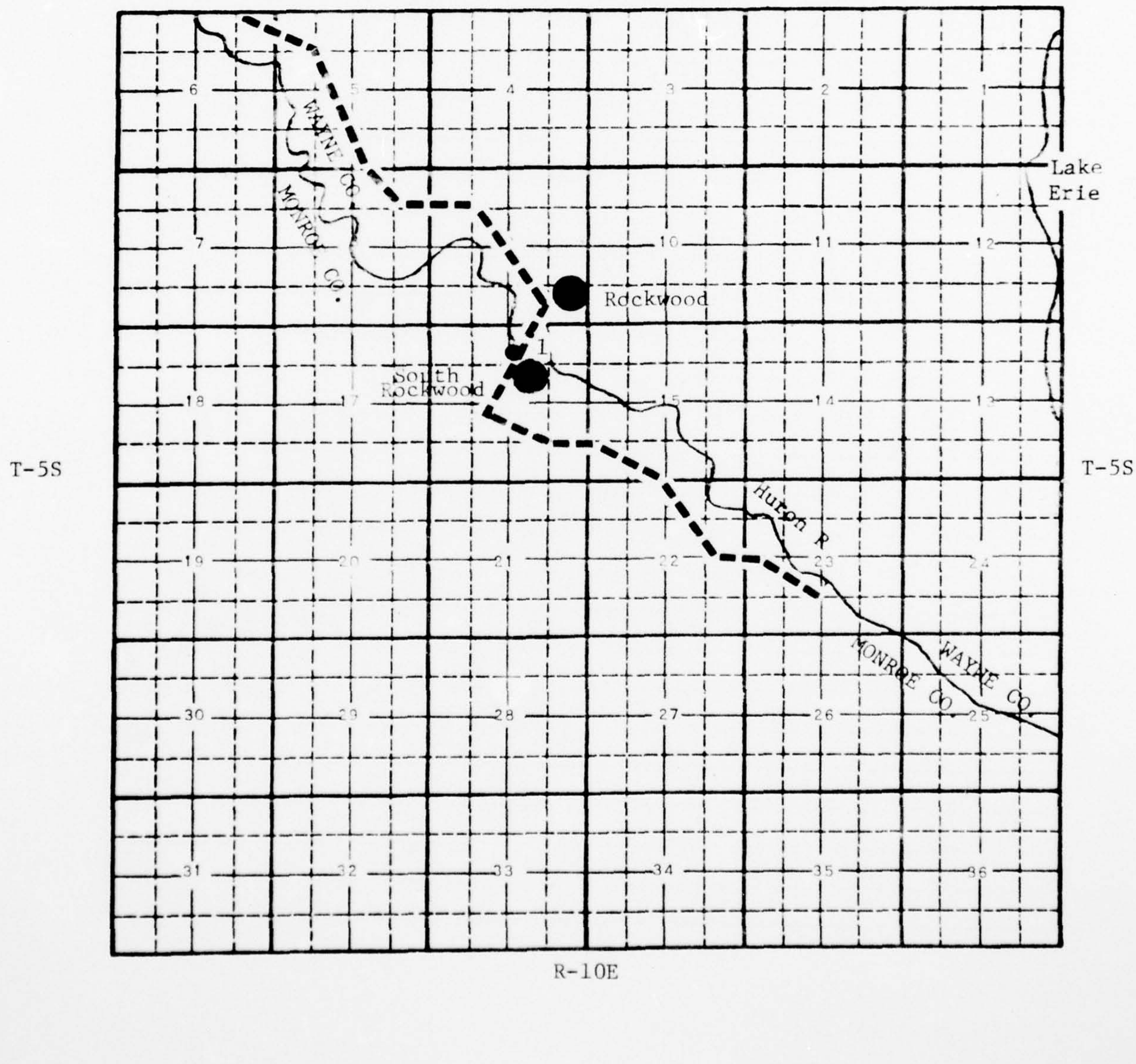
NOTES: SEC 22 of T-4S - R-10E (See 7-8)

BROWNSTOWN TWP.



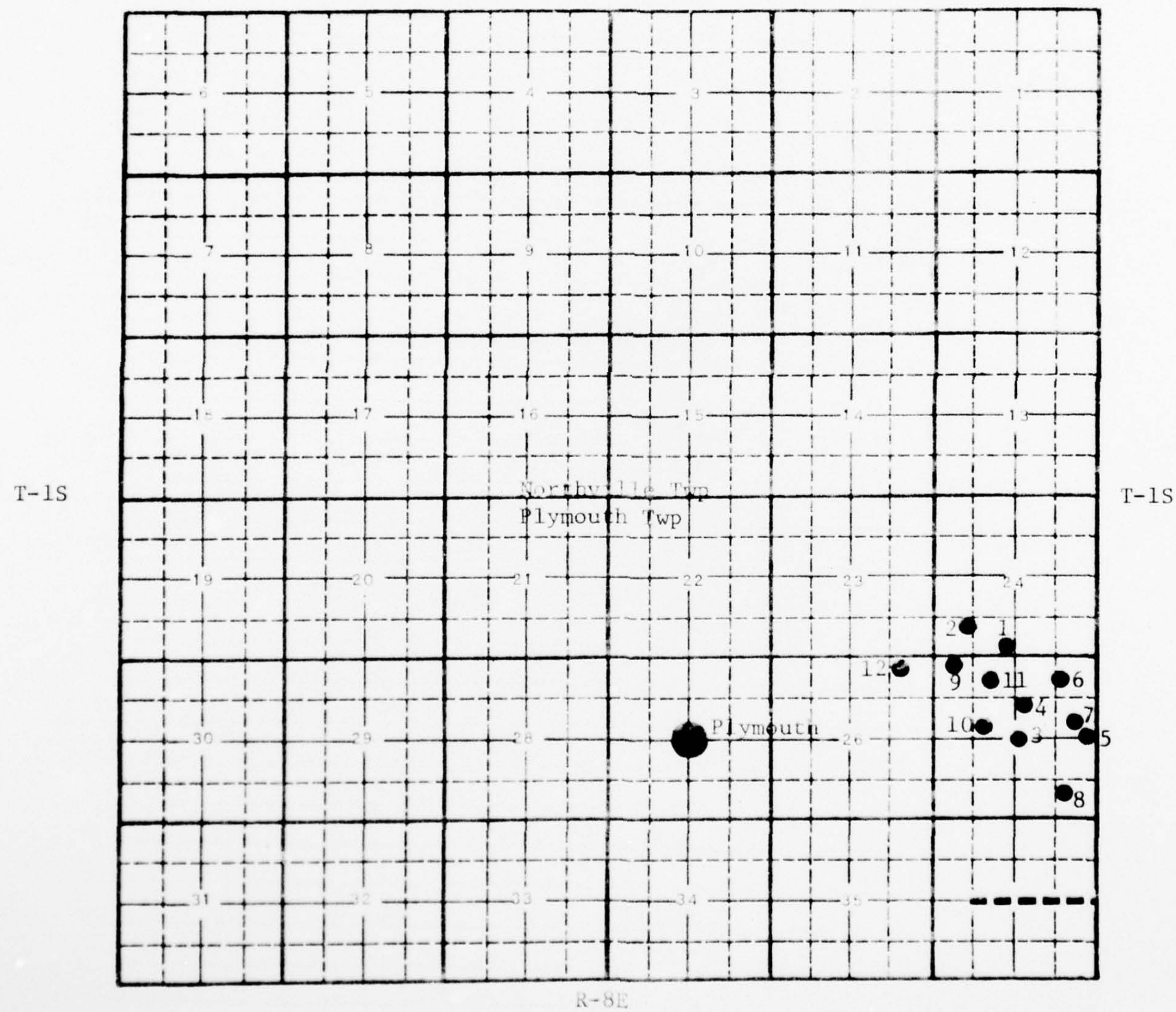
TOWNSHIP 5S **RANGE** 10E **COUNTY** WAYNE / MONROE **STATE** MICHIGAN

NOTES: UPPER ROUGE RIVER - TELEGRAPH RD. TUNNEL 8-8



TOWNSHIP 1S RANGE 8E COUNTY WAYNE STATE MICHIGAN

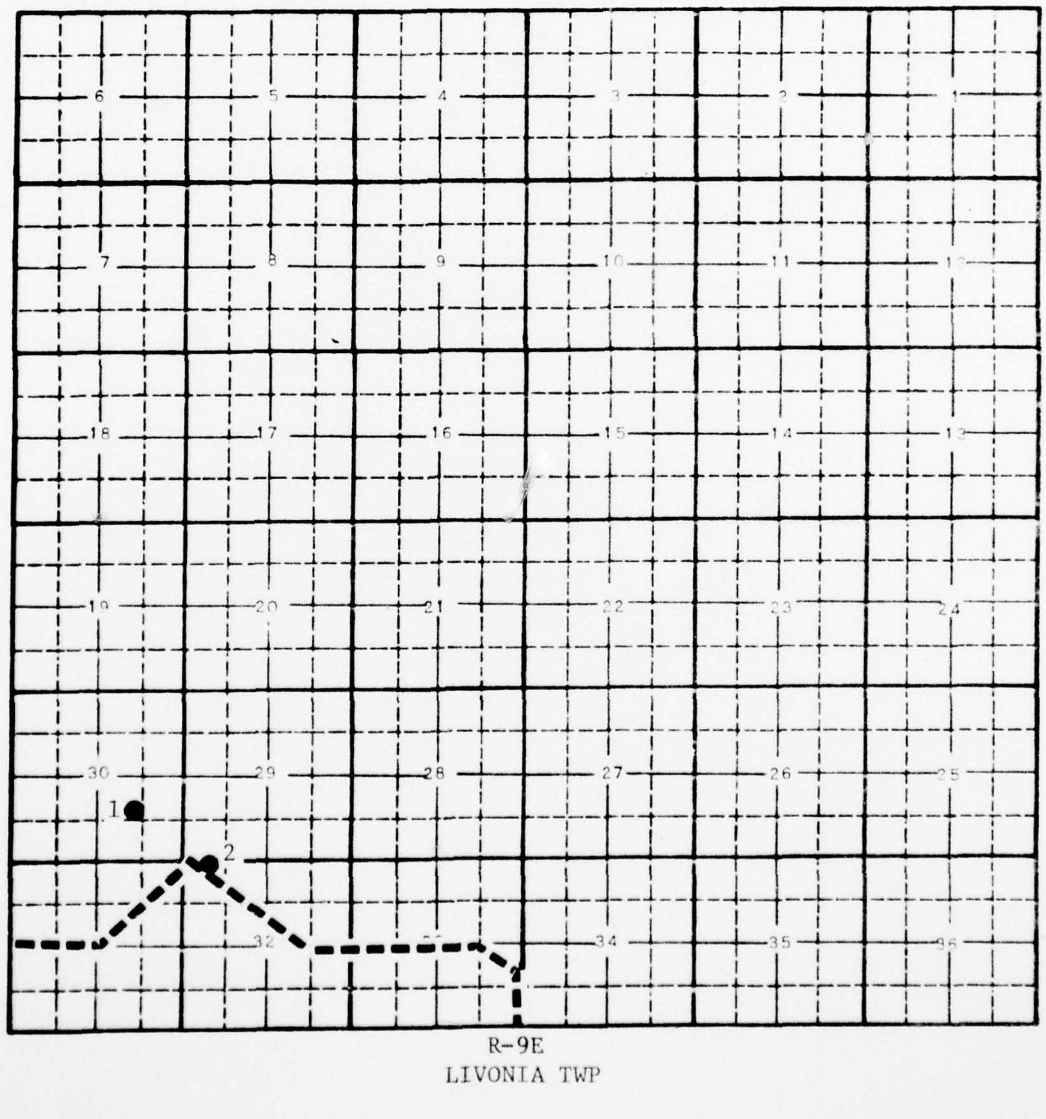
NOTES: ROUGE RIVER TUNNEL 1-5



TOWNSHIP 1S **RANGE** 9E **COUNTY** WAYNE **STATE** MICHIGAN

NOTES: ROUGE RIVER TUNNEL 2-5

T-1S



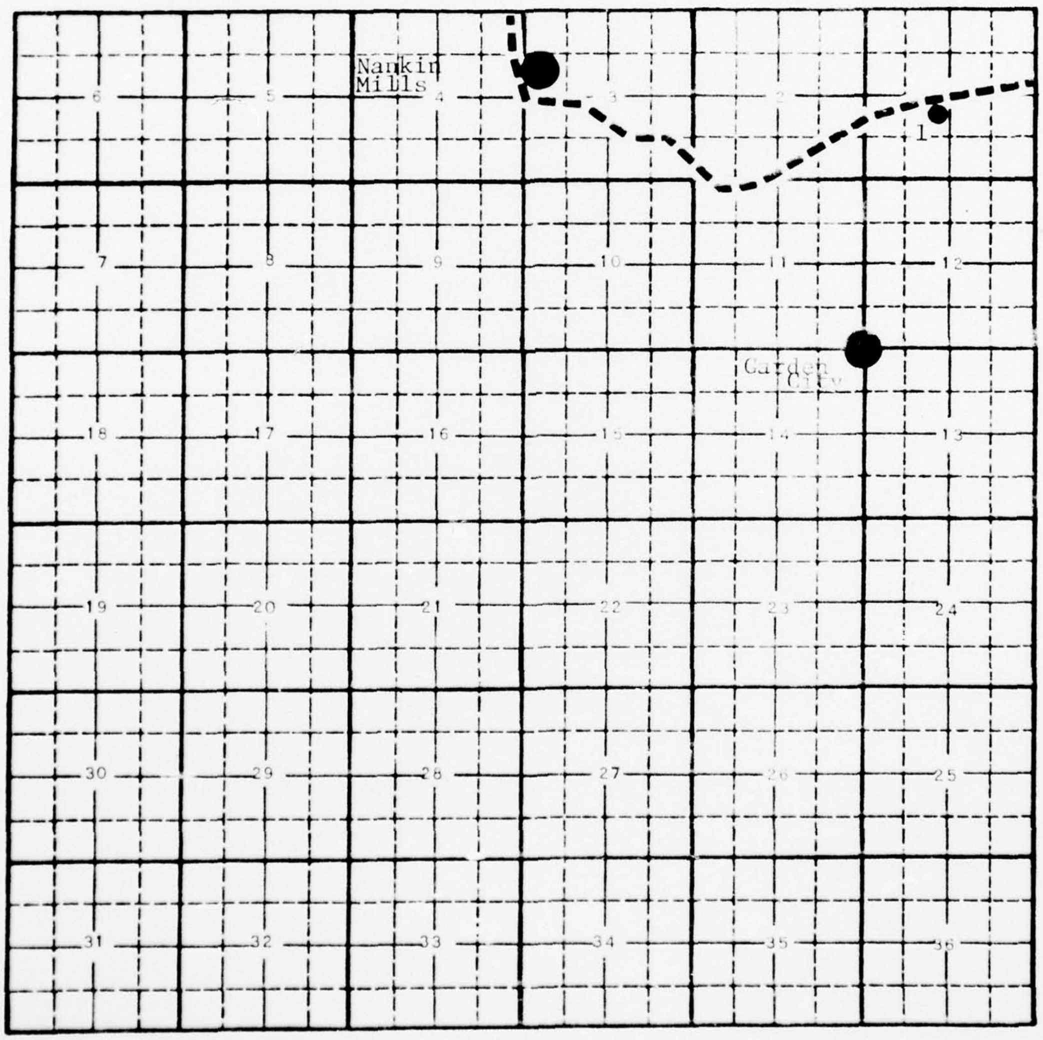
T-1S

R-9E
LIVONIA TWP

TOWNSHIP 2S RANGE 9E COUNTY WAYNE STATE MICHIGAN

NOTES: ROUGE RIVER TUNNEL 3-5

T-2S

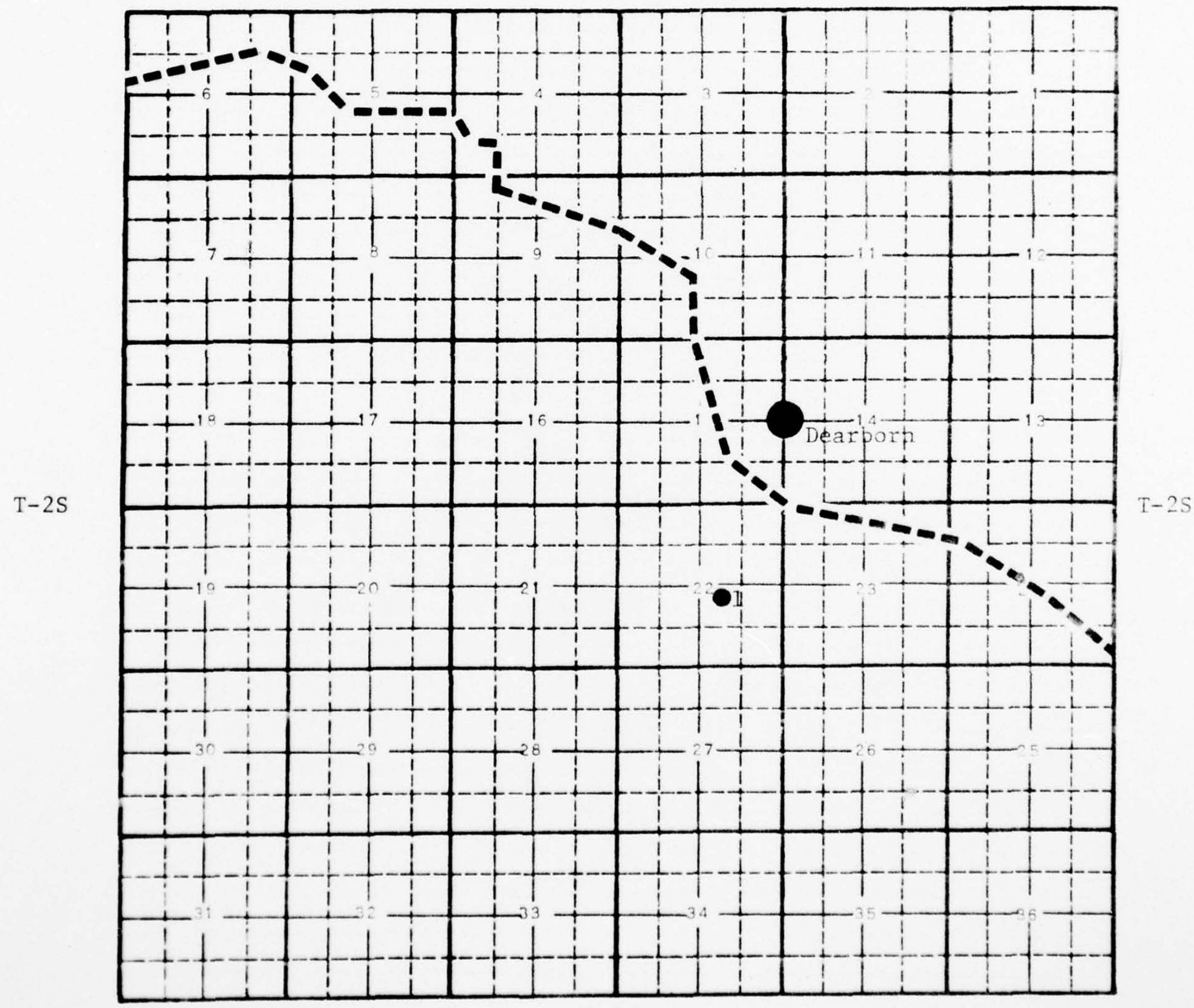


T-2S

R-9E
NANKIN TWP

TOWNSHIP 2S **RANGE** 10E **COUNTY** WAYNE **STATE** MICHIGAN

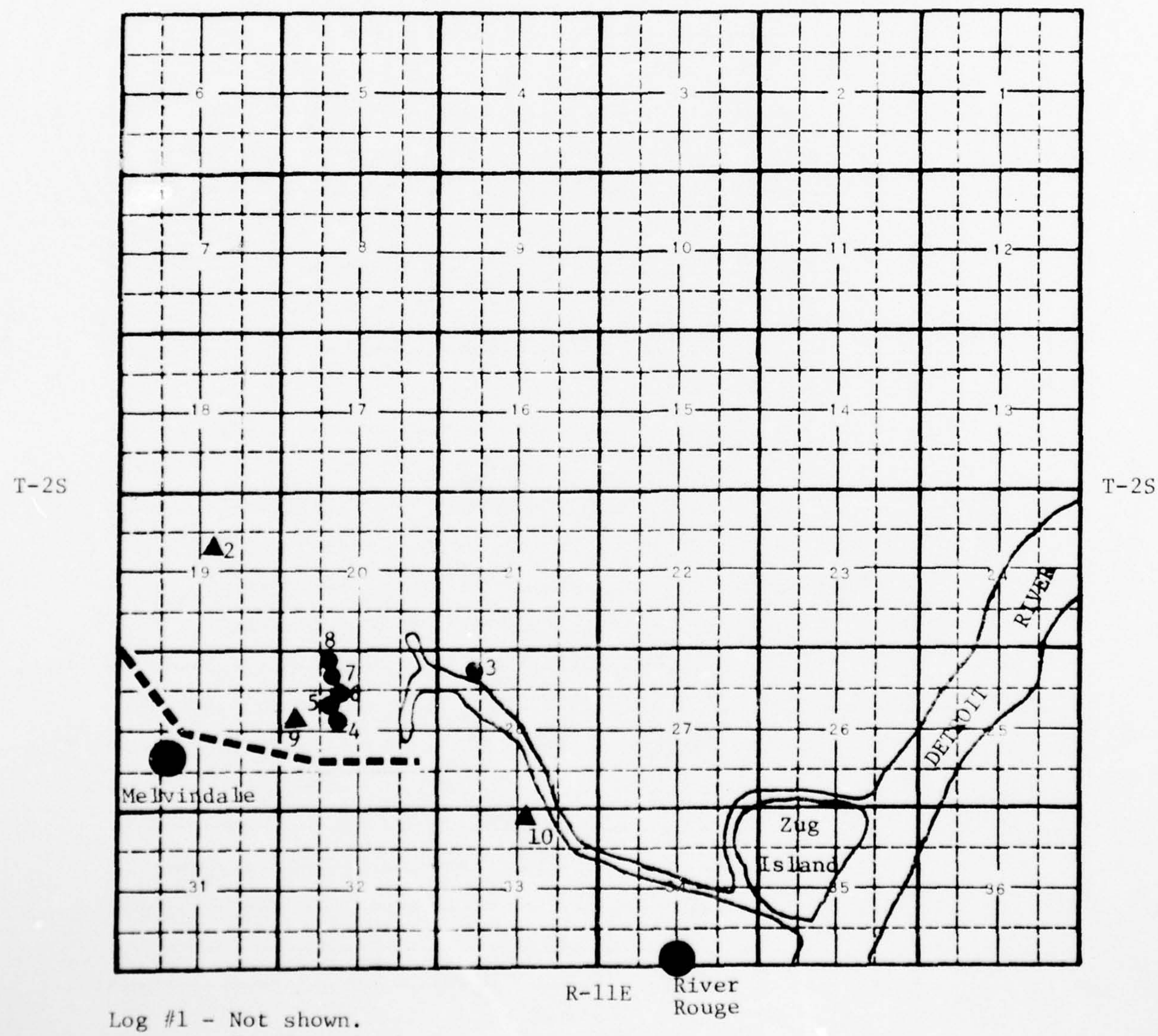
NOTES: ROUGE RIVER TUNNEL 4-5



R-10E
DEARBORN TWP

TOWNSHIP 2-S RANGE 11E COUNTY WAYNE STATE MICHIGAN

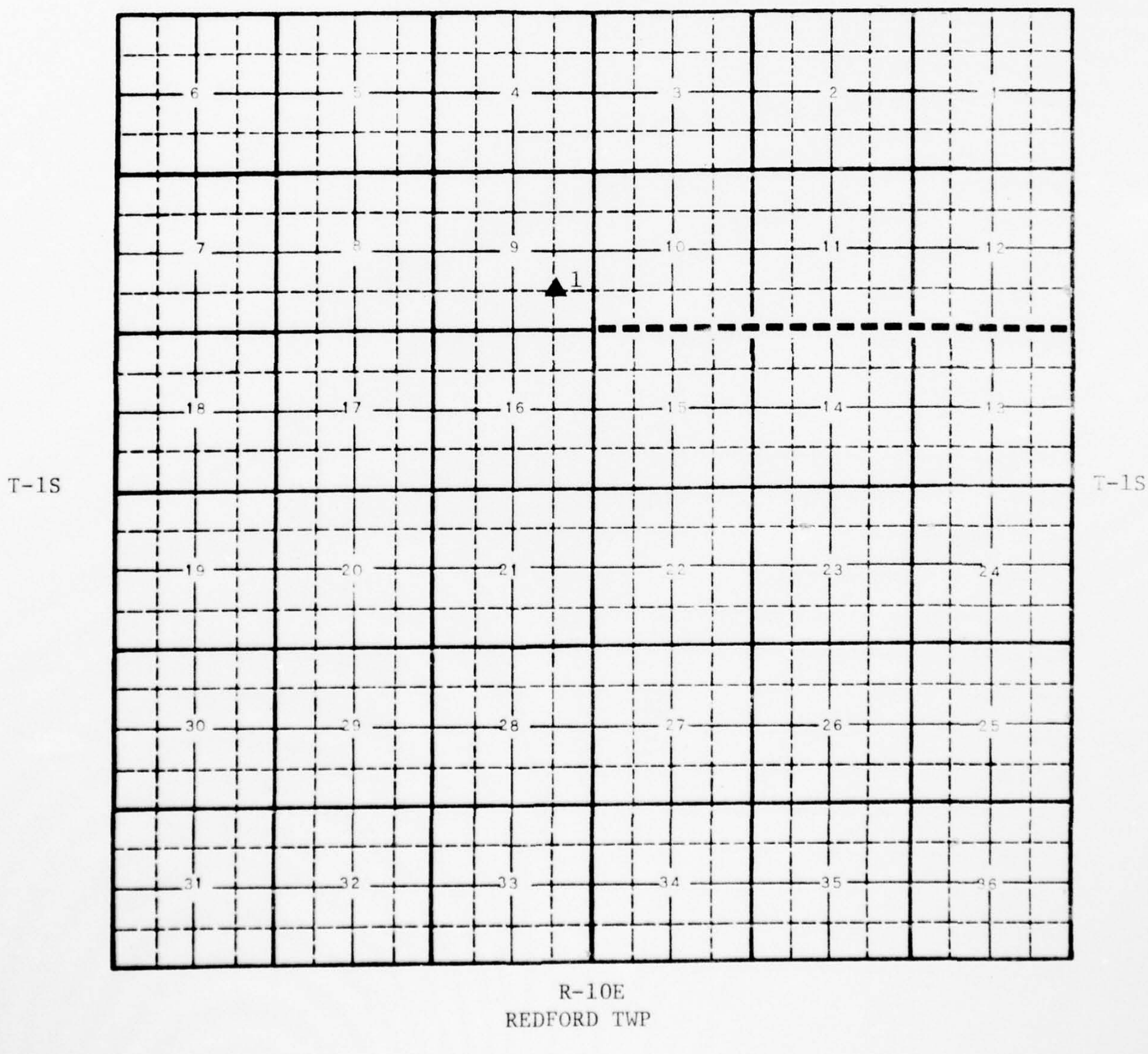
NOTES: ROUGE RIVER TUNNEL 5-5



Log #1 - Not shown.
See Description

TOWNSHIP 1S **RANGE** 10E **COUNTY** WAYNE **STATE** MICHIGAN

NOTES: SIX MILE RD - CONNER CREEK TUNNEL 1-4



AD-A041 124 WAYNE STATE UNIV DETROIT MICH DEPT OF GEOLOGY F/G 13/2

GEOLOGIC CONSIDERATIONS FOR SOUTHEASTERN MICHIGAN WASTEWATER MA--ETC(U)

FEB 73 A J MOZOLA DACW35-72-C-0008

UNCLASSIFIED NL

2 OF 2

AD A041124

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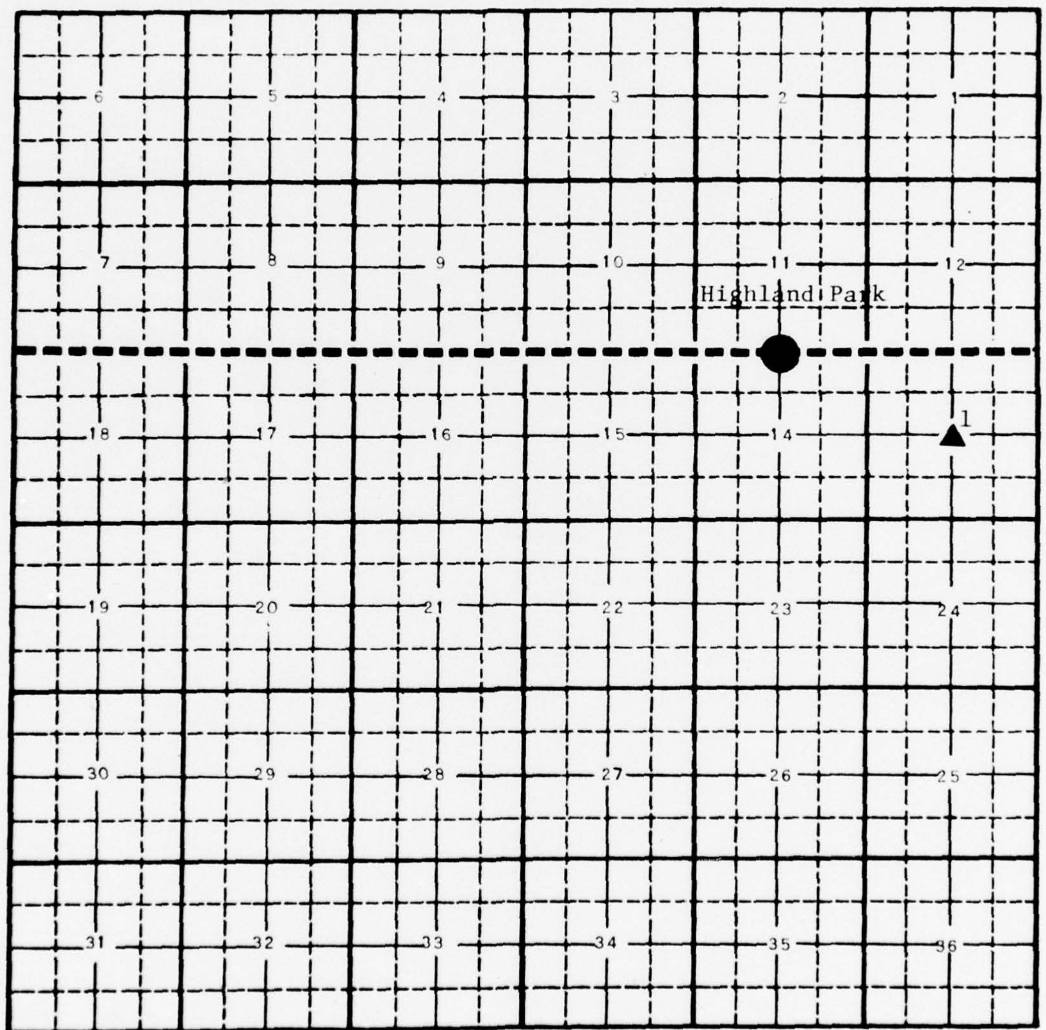
DATE FILMED

7-77

TOWNSHIP 1S **RANGE** 11E **COUNTY** WAYNE **STATE** MICHIGAN

NOTES: SIX MILE ROAD - CONNER CREEK TUNNEL 2-4



T-1S

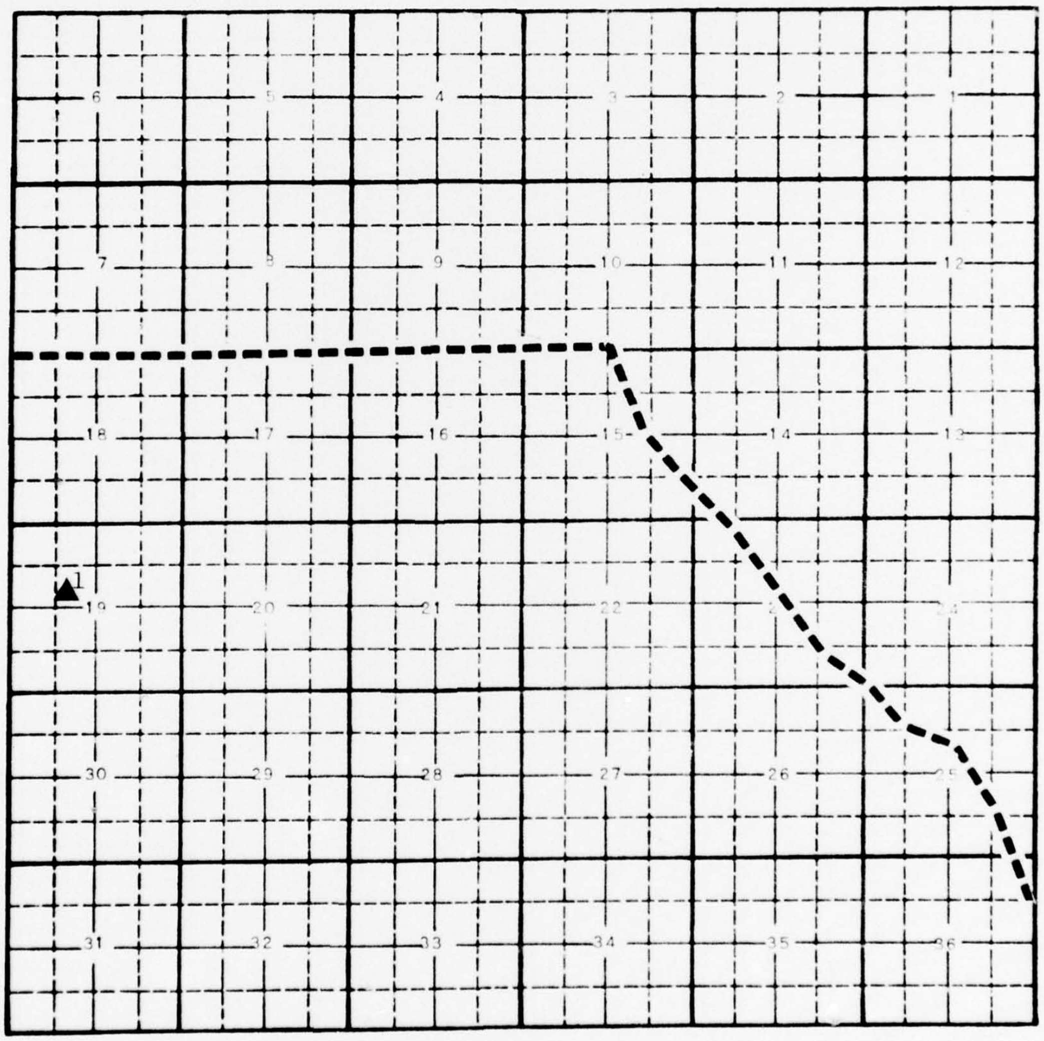
T-1S

R-11E

TOWNSHIP 1S **RANGE** 12E **COUNTY** WAYNE **STATE** MICHIGAN

NOTES: SIX MILE ROAD - CONNER CREEK TUNNEL 3-4

T-1S



T-1S

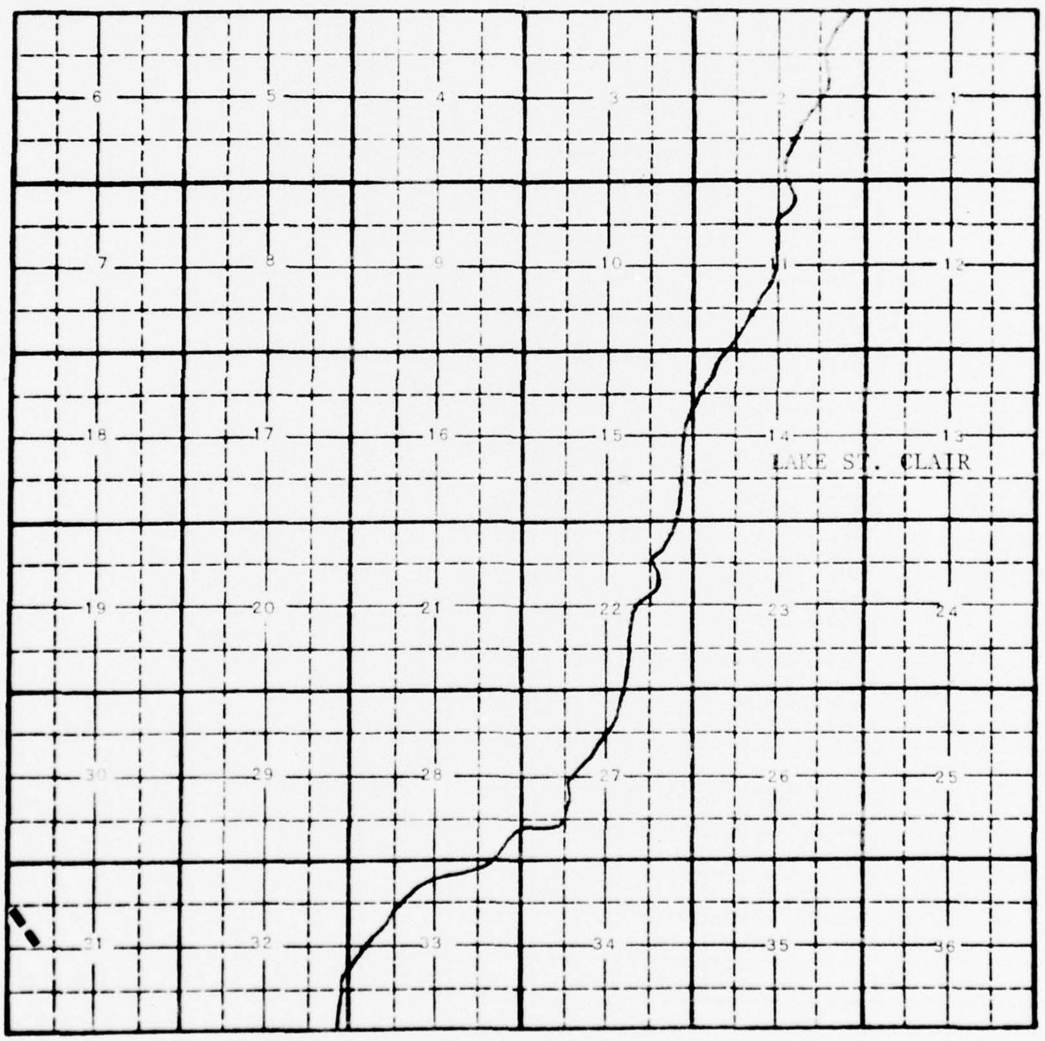
R-12E

TOWNSHIP 1S RANGE 13E COUNTY WAYNE STATE MICHIGAN

NOTES: SIX MILE ROAD - CONNER CREEK TUNNEL 4-4

NO RECORDS OF OIL & GAS WELLS

T-1S

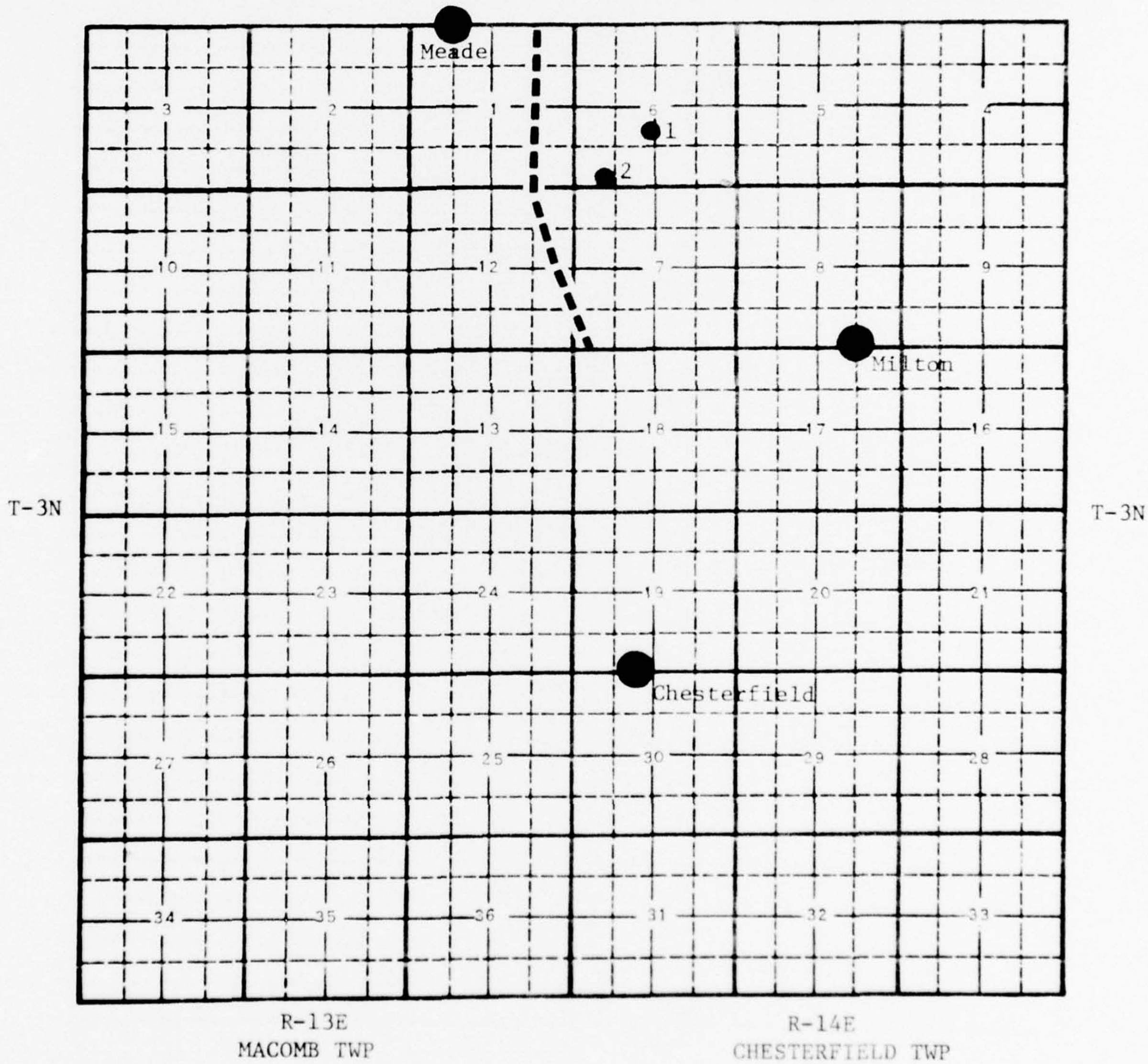


T-1S

R-13E

TOWNSHIP 3N **RANGE** 13-14E **COUNTY** MACOMB **STATE** MICHIGAN

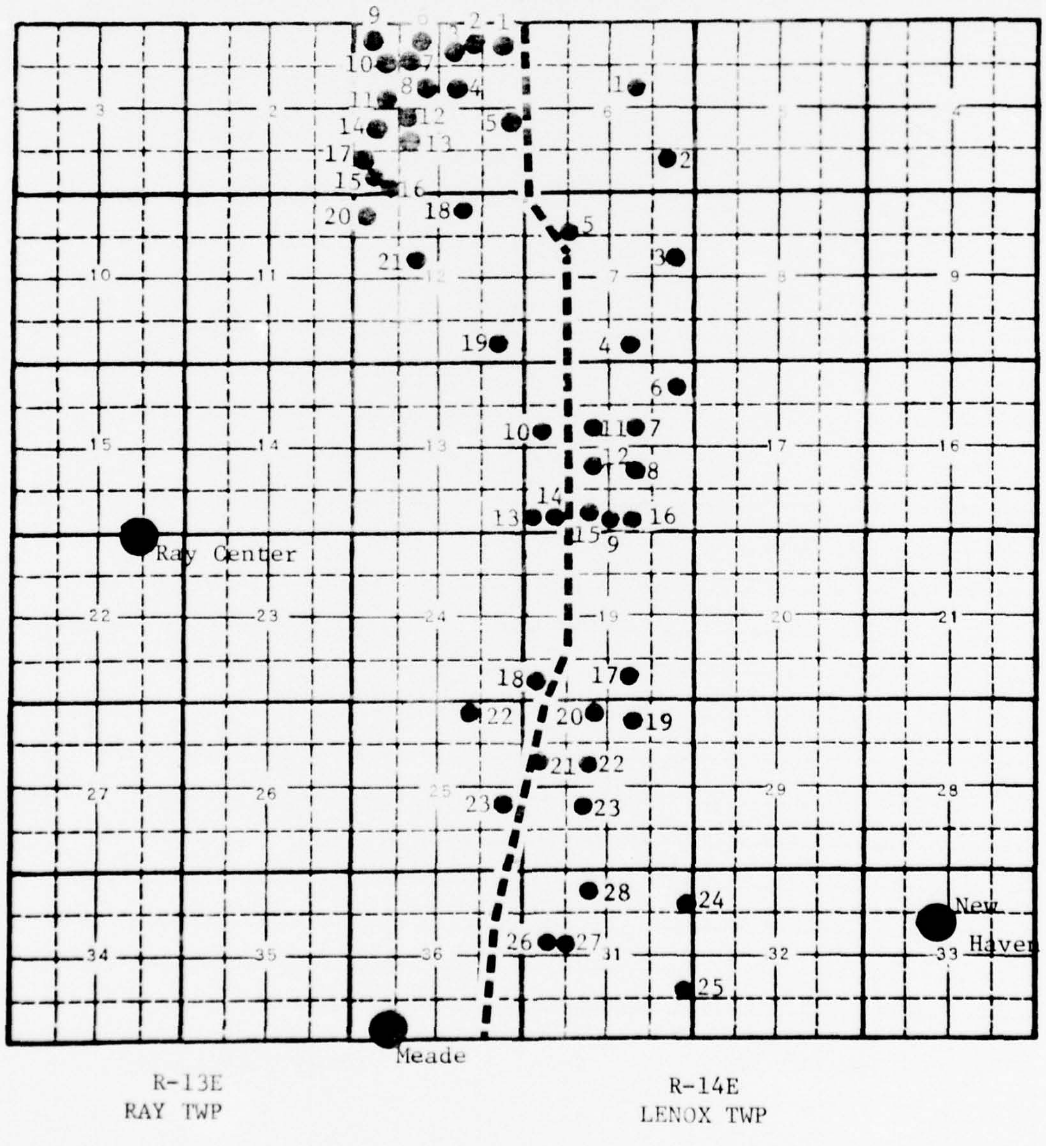
NOTES: MACOMB COUNTY TO HURON COUNTY TUNNEL 1-13



TOWNSHIP 4N RANGE 13-14E COUNTY MACOMB STATE MICHIGAN

NOTES: MACOMB COUNTY TO HURON COUNTY TUNNEL 2-13

T-4N



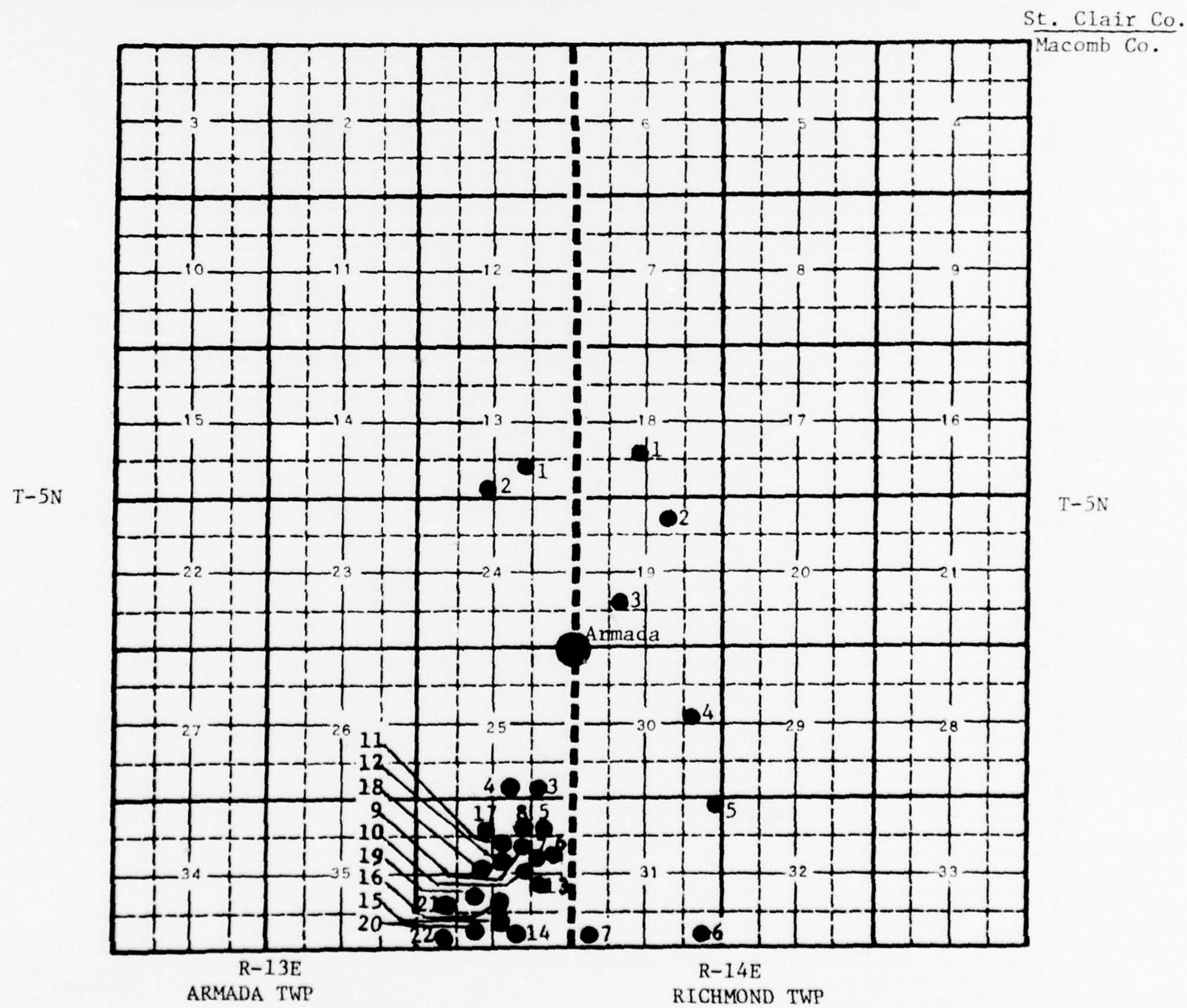
T-4N

R-13E
RAY TWP

R-14E
LENOX TWP

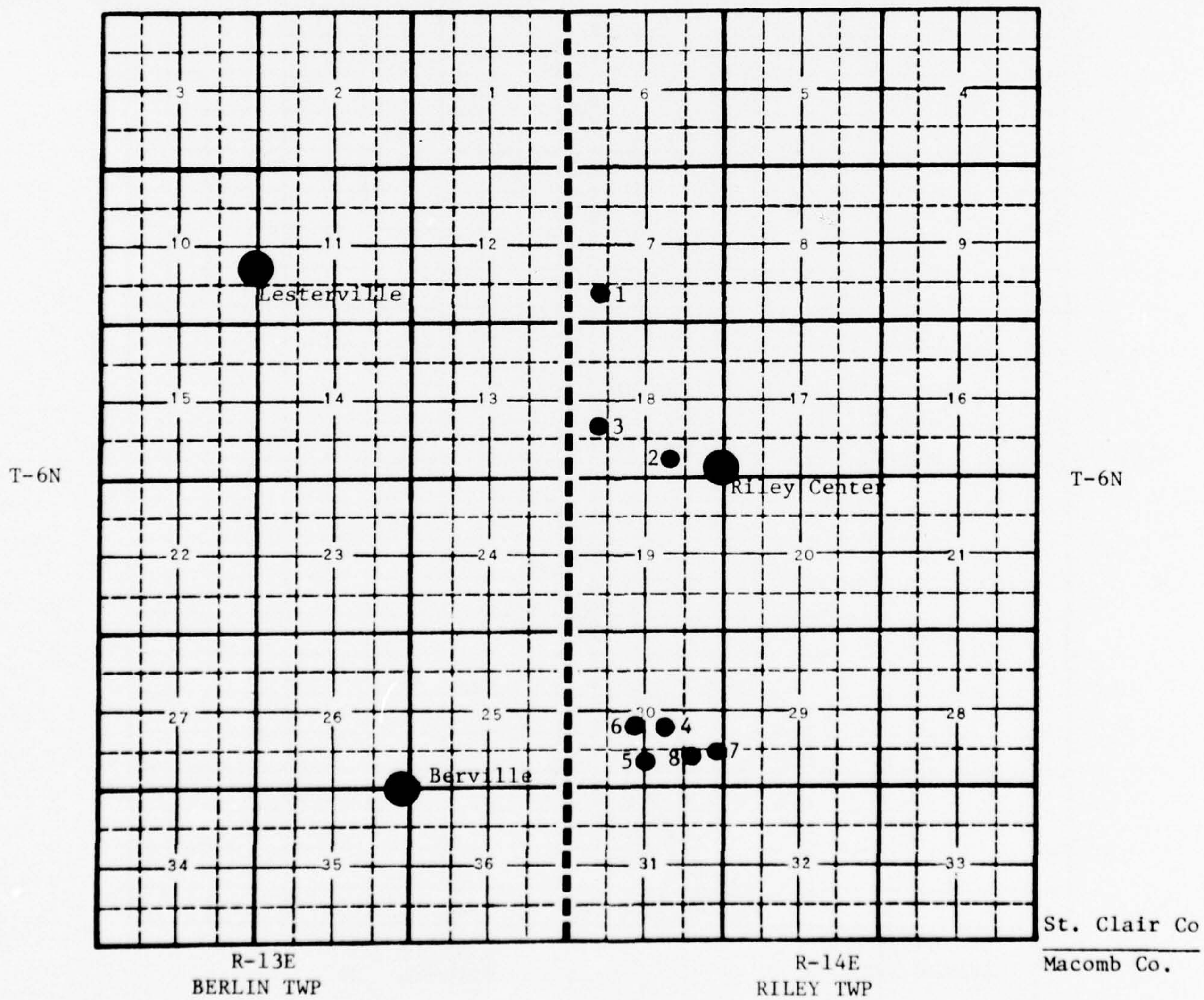
TOWNSHIP 5N **RANGE** 13-14E **COUNTY** MACOMB **STATE** MICHIGAN

NOTES: MACOMB COUNTY TO HURON COUNTY TUNNEL 3-13



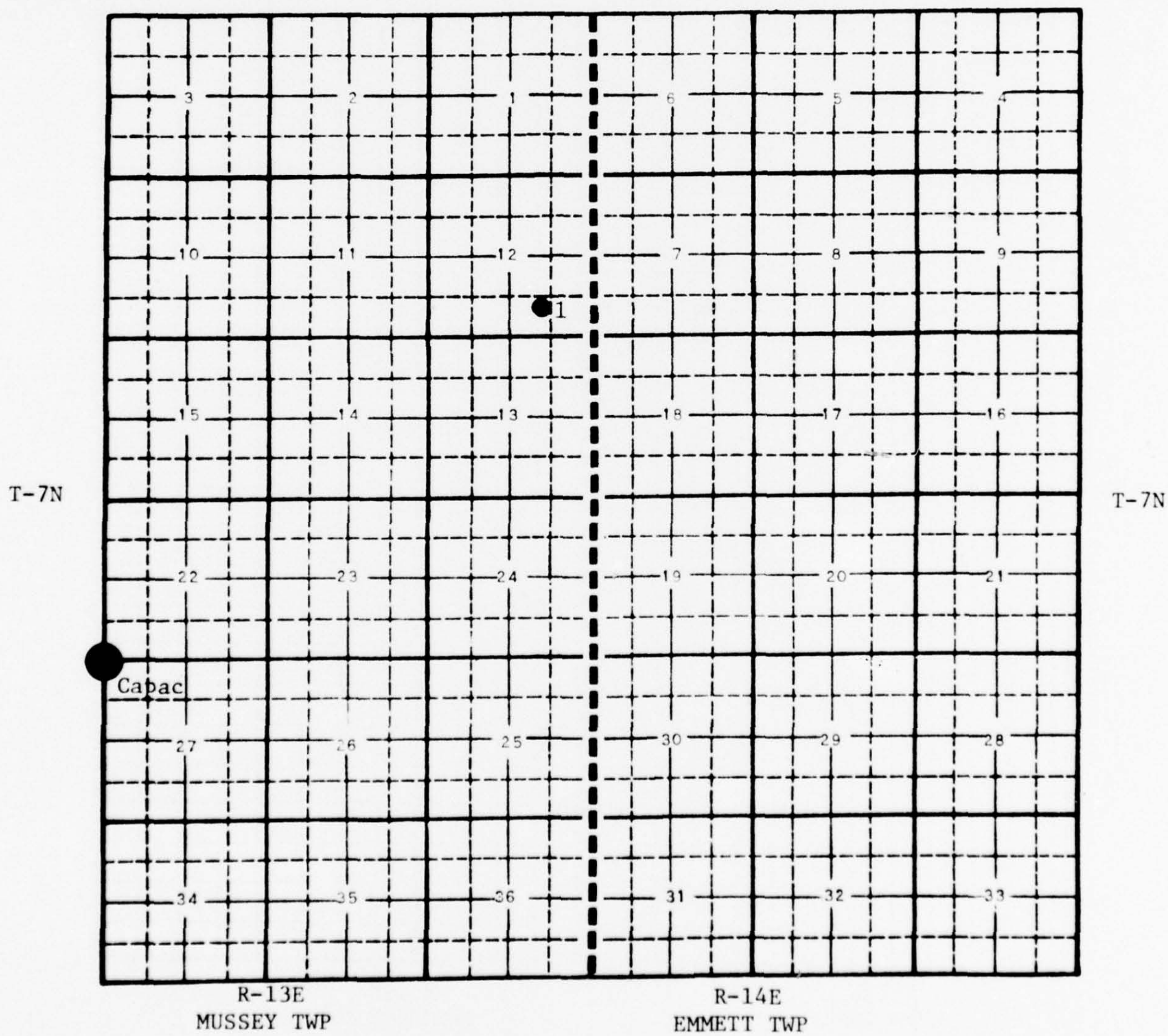
TOWNSHIP 6N **RANGE** 13-14E **COUNTY** ST. CLAIR **STATE** MICHIGAN

NOTES: MACOMB COUNTY TO HURON COUNTY TUNNEL 4-13



TOWNSHIP 7N **RANGE** 13-14E **COUNTY** ST. CLAIR **STATE** MICHIGAN

NOTES: MACOMB COUNTY TO HURON COUNTY TUNNEL 5-13

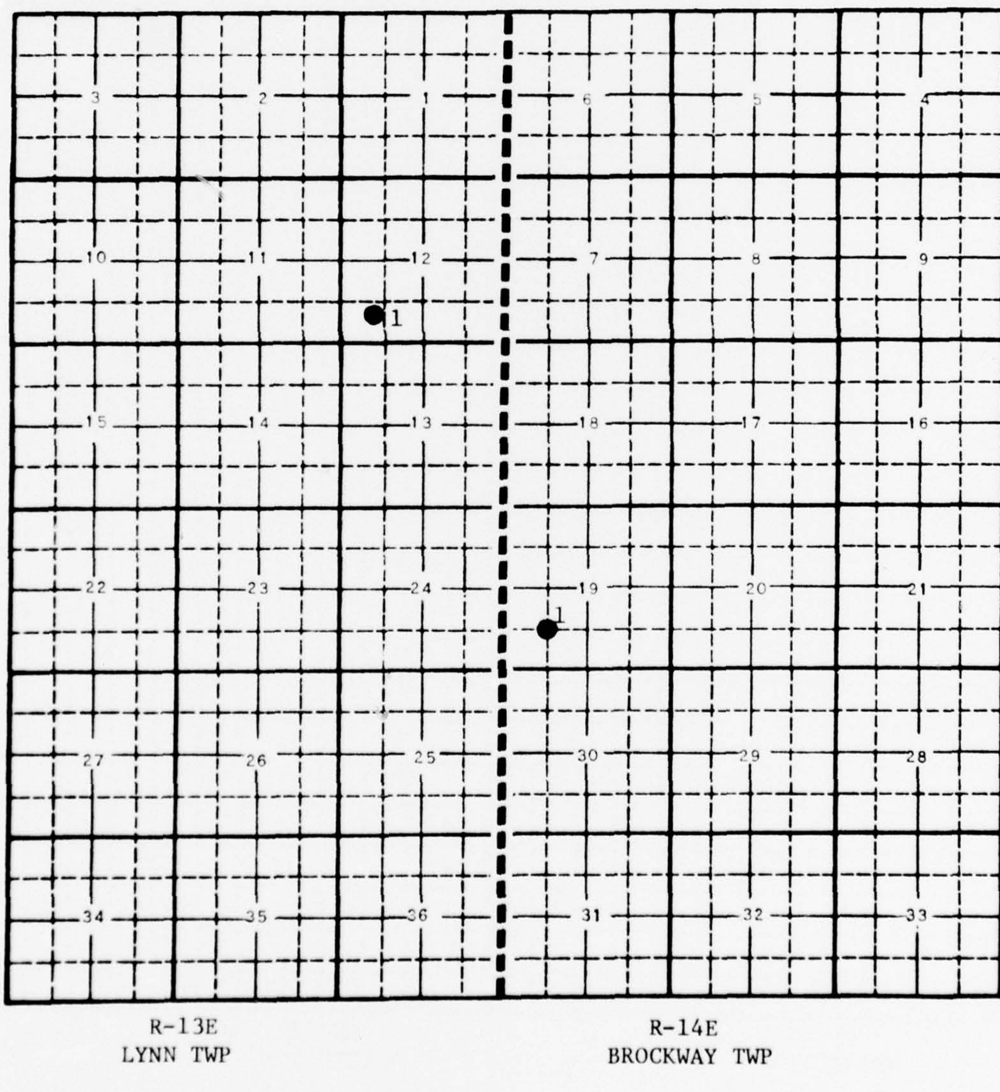


TOWNSHIP 8N **RANGE** 13-14E **COUNTY** ST. CLAIR **STATE** MICHIGAN

NOTES: MACOMB COUNTY TO HURON COUNTY TUNNEL 6-13

Sanilac Co.
St. Clair Co.

T-8N



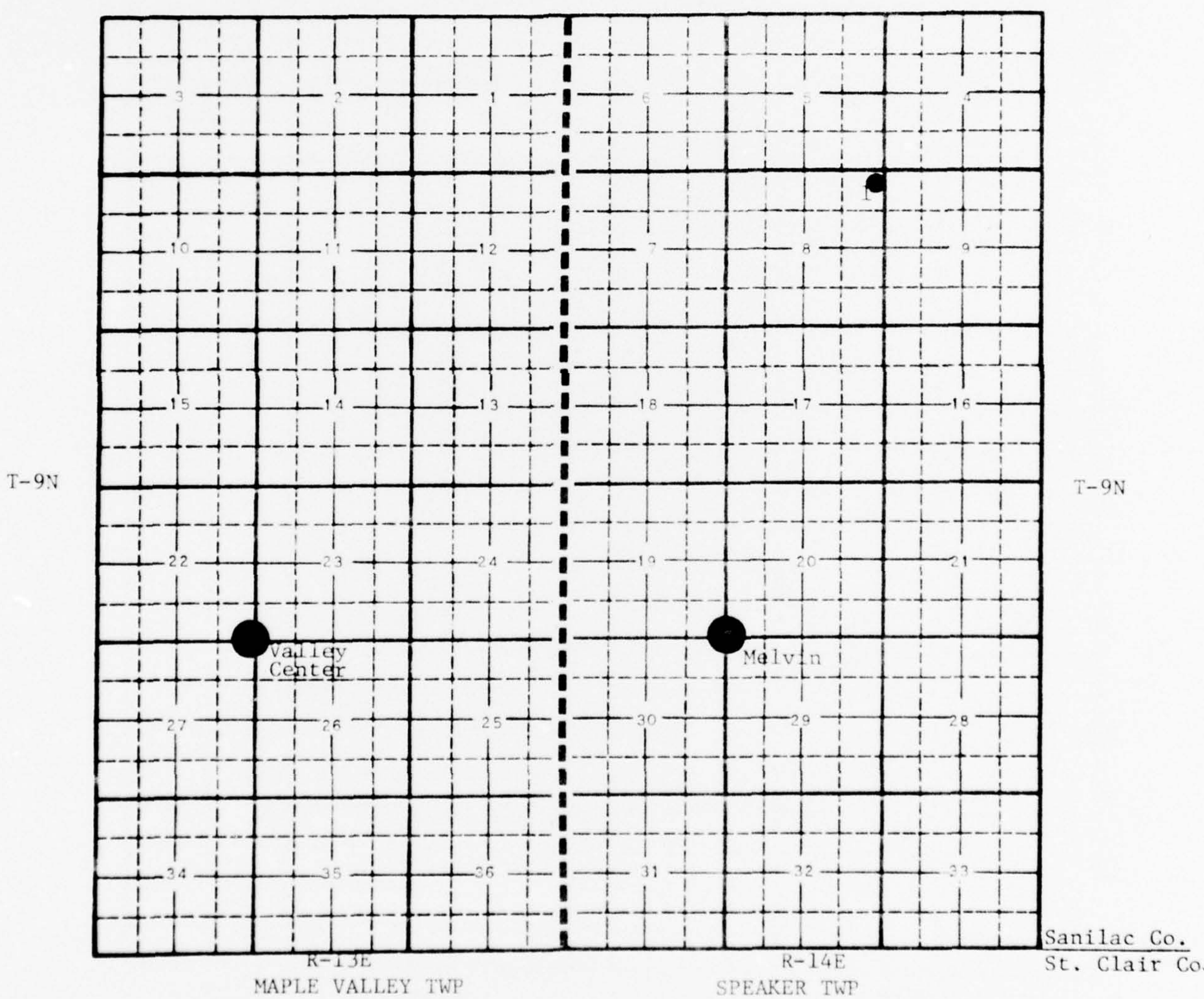
T-8N

R-13E
LYNN TWP

R-14E
BROCKWAY TWP

TOWNSHIP 9N **RANGE** 13-14E **COUNTY** SANILAC **STATE** MICHIGAN

NOTES: MACOMB COUNTY TO HURON COUNTY TUNNEL 7-13

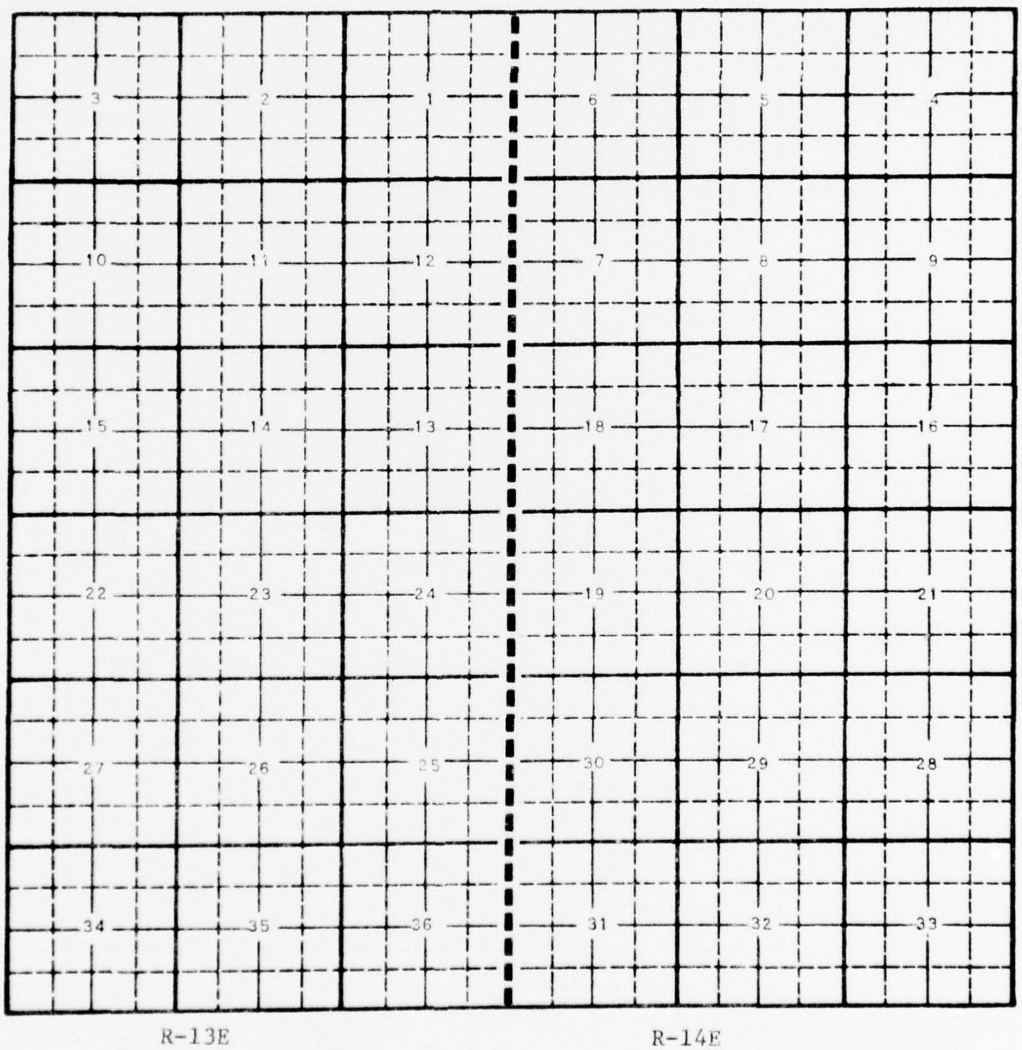


TOWNSHIP 10N **RANGE** 13-14E **COUNTY** SANILAC **STATE** MICHIGAN

NOTES: MACOMB COUNTY TO HURON COUNTY TUNNEL 8-13

NO RECORDS OF OIL & GAS WELLS

T-10N



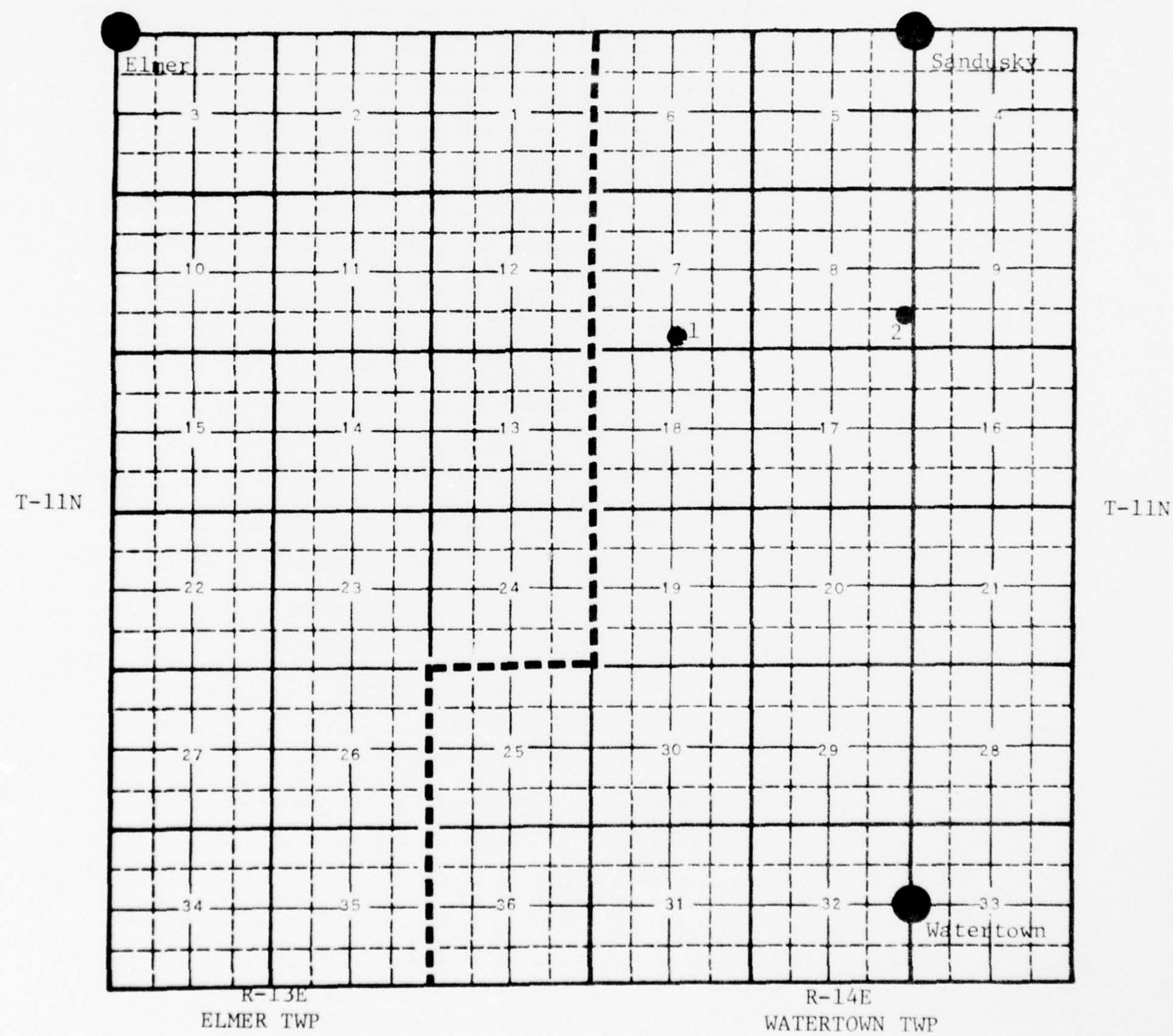
T-10N

R-13E
Flynn Twp

R-14E
Elk Twp

TOWNSHIP 11N **RANGE** 13-14E **COUNTY** SANILAC **STATE** MICHIGAN

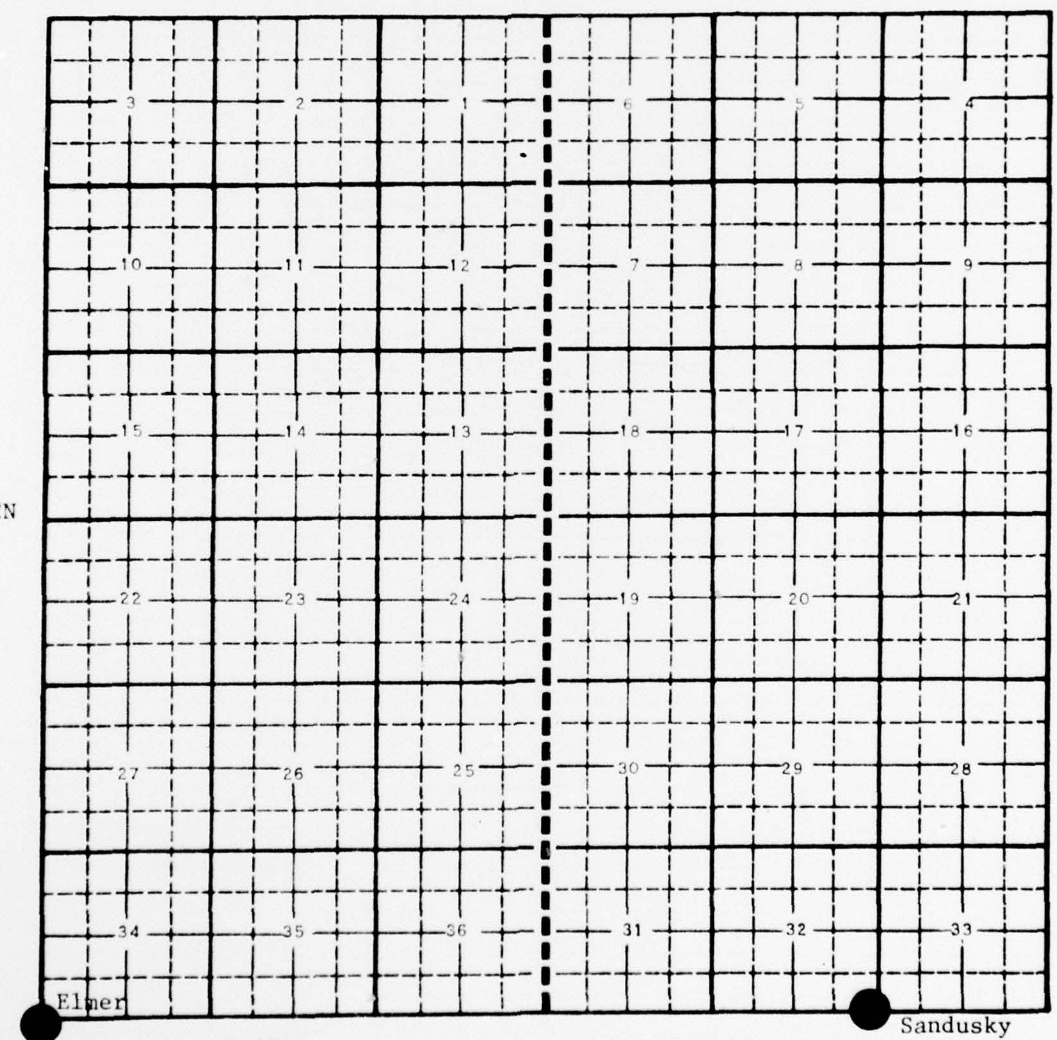
NOTES: MACOMB COUNTY TO HURON COUNTY TUNNEL 9-13



TOWNSHIP 12 N **RANGE** 13-14E **COUNTY** SANILAC **STATE** MICHIGAN

NOTES: MACOMB COUNTY TO HURON COUNTY TUNNEL 10-13

NO RECORDS OF OIL & GAS WELLS



T-12N

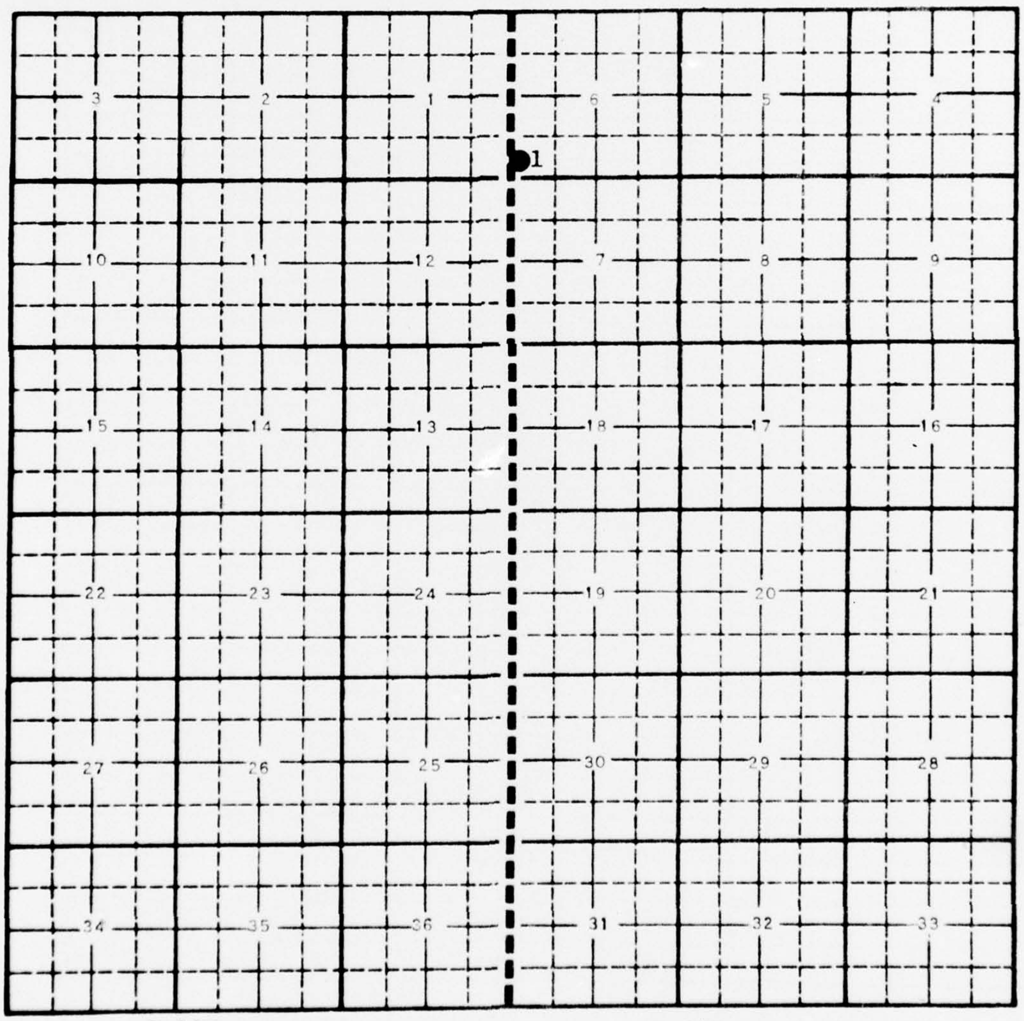
T-12N

R-13E
MOORE TWP

R-14E
CUSTER TWP

TOWNSHIP 13 N **RANGE** 13-14E **COUNTY** SANILAC **STATE** MICHIGAN

NOTES: MACOMB COUNTY TO HURON COUNTY TUNNEL 11-13



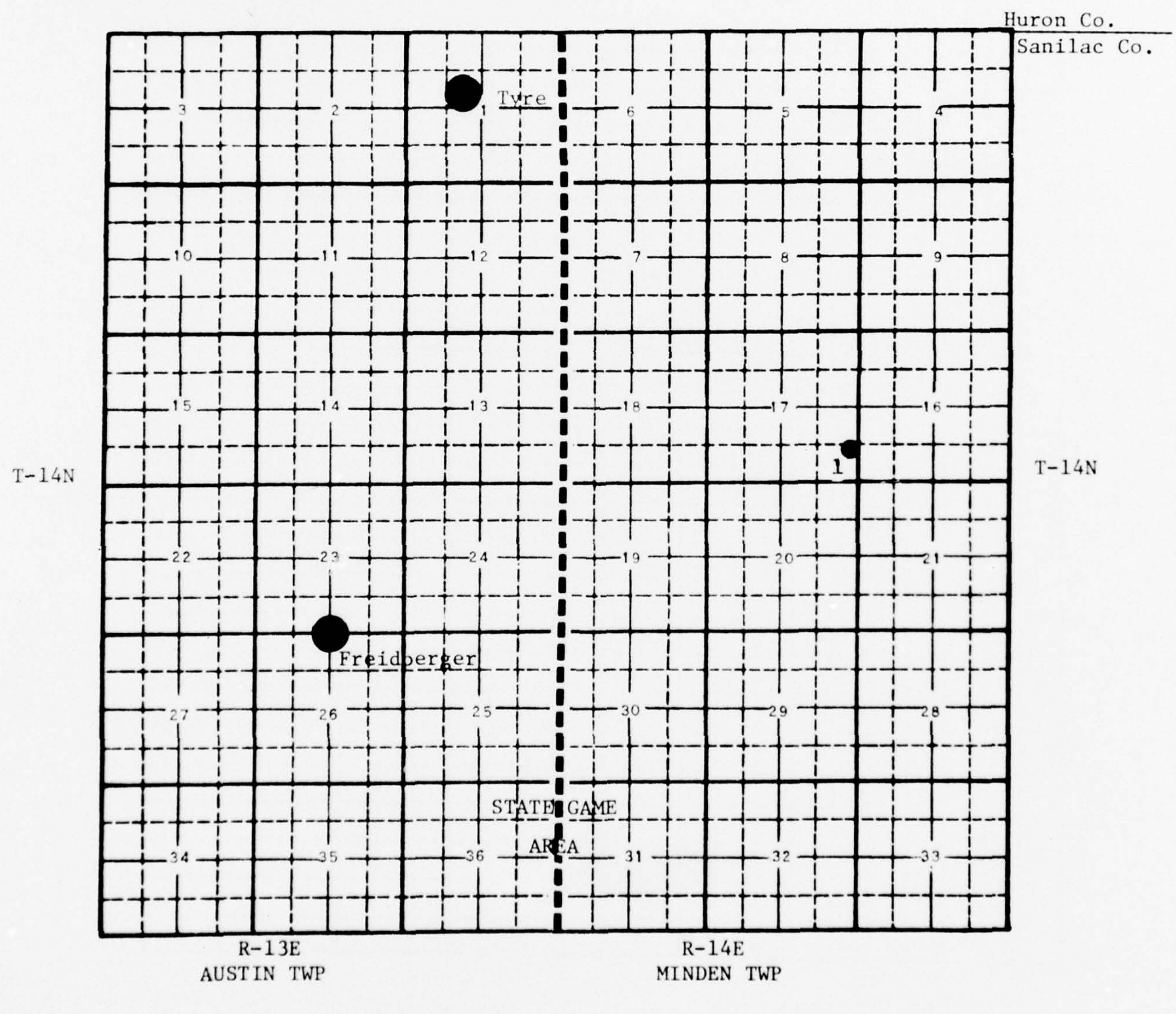
T-13N T-13N

R-13E
ARGYLE TWP

R-14E
WHEATLAND TWP

TOWNSHIP 14N **RANGE** 13-14E **COUNTY** SANILAC **STATE** MICHIGAN

NOTES: MACOMB COUNTY TO HURON COUNTY TUNNEL 12-13

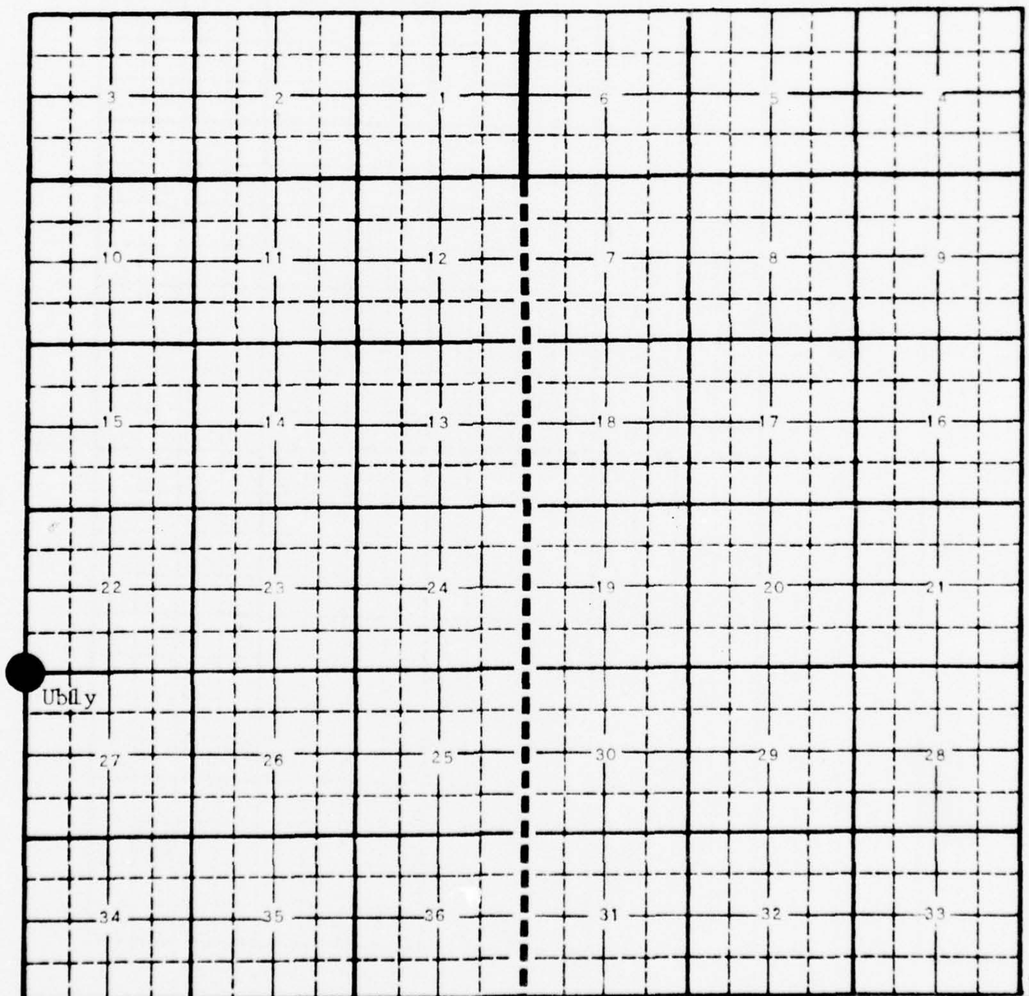


TOWNSHIP 15N **RANGE** 13-14E **COUNTY** HURON **STATE** MICHIGAN

NOTES: MACOMB COUNTY TO HURON COUNTY TUNNEL 13-13

NO RECORDS OF OIL & GAS WELLS

T-15N



T-15N

R-13E
BINGHAM TWP

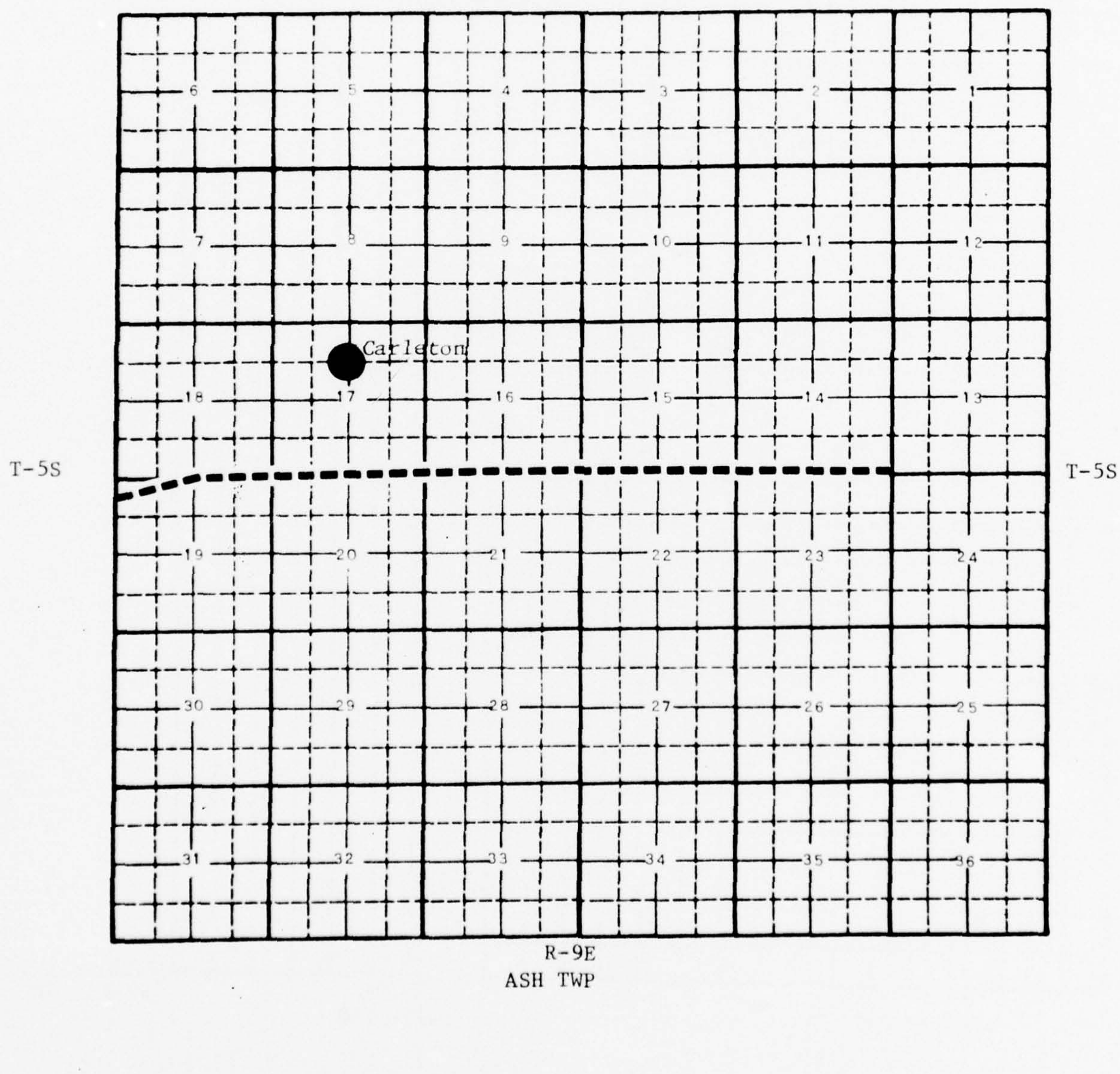
R-14E
PARIS TWP

Huron Co.
Sanilac Co.

TOWNSHIP 5S **RANGE** 9E **COUNTY** MONROE **STATE** MICHIGAN

NOTES: MONROE COUNTY TO HILLSDALE COUNTY TUNNEL 1-13

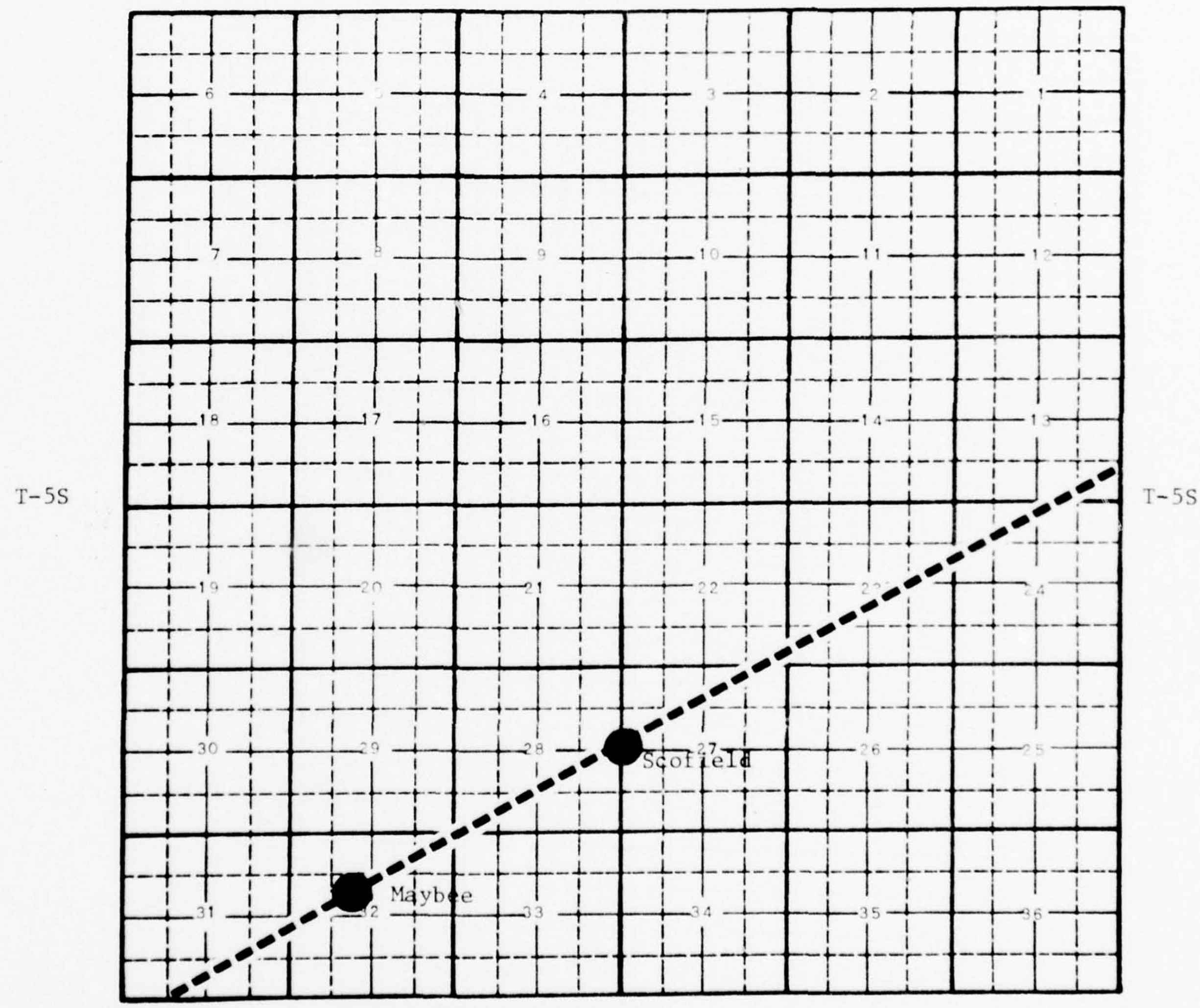
NO OIL & GAS WELL LOGS



TOWNSHIP 5S **RANGE** 8E **COUNTY** MONROE **STATE** MICHIGAN

NOTES: MONROE COUNTY TO HILLSDALE COUNTY TUNNEL 2-13

NO OIL & GAS WELL LOGS



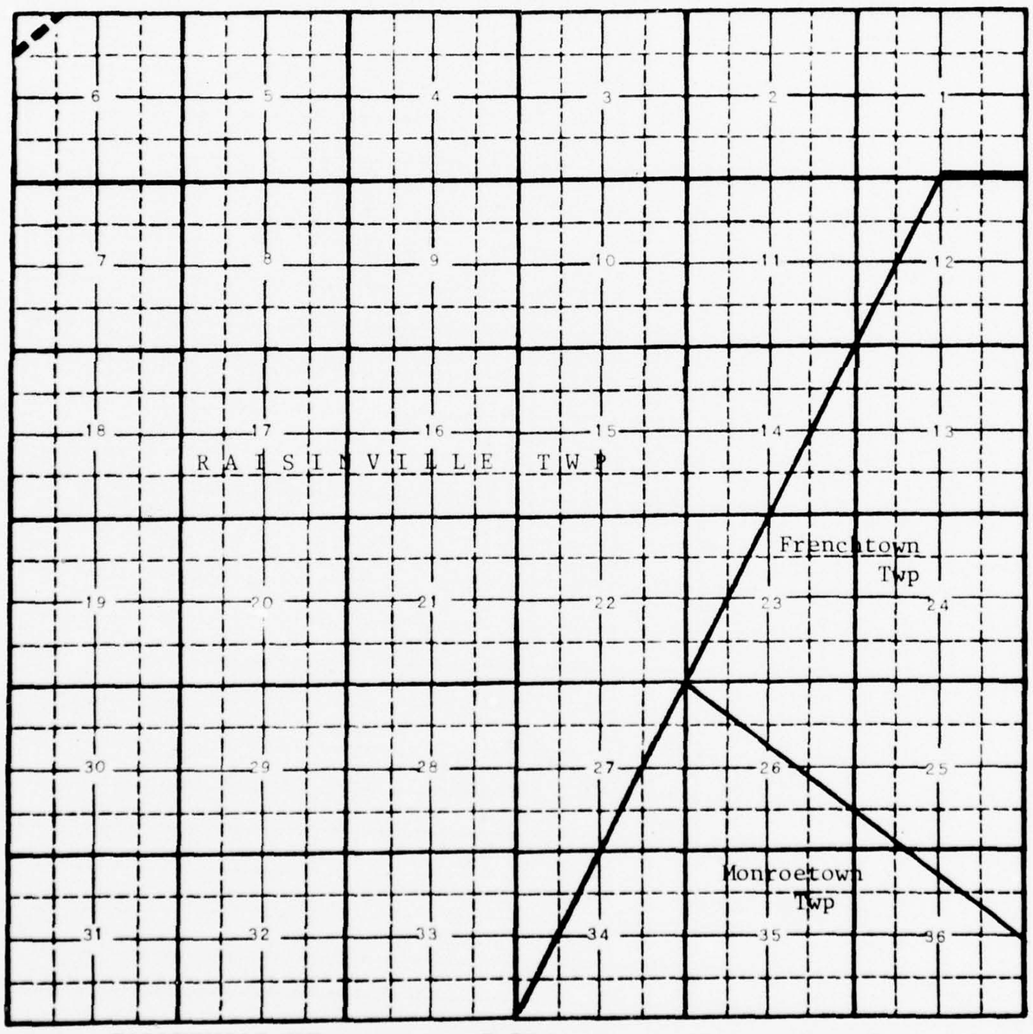
R-8E
EXETER TWP

TOWNSHIP 6S RANGE 8E COUNTY MONROE STATE MICHIGAN

NOTES: MONROE COUNTY TO HILLSDALE COUNTY TUNNEL 3-13

NO OIL & GAS WELL LOGS

T-6S

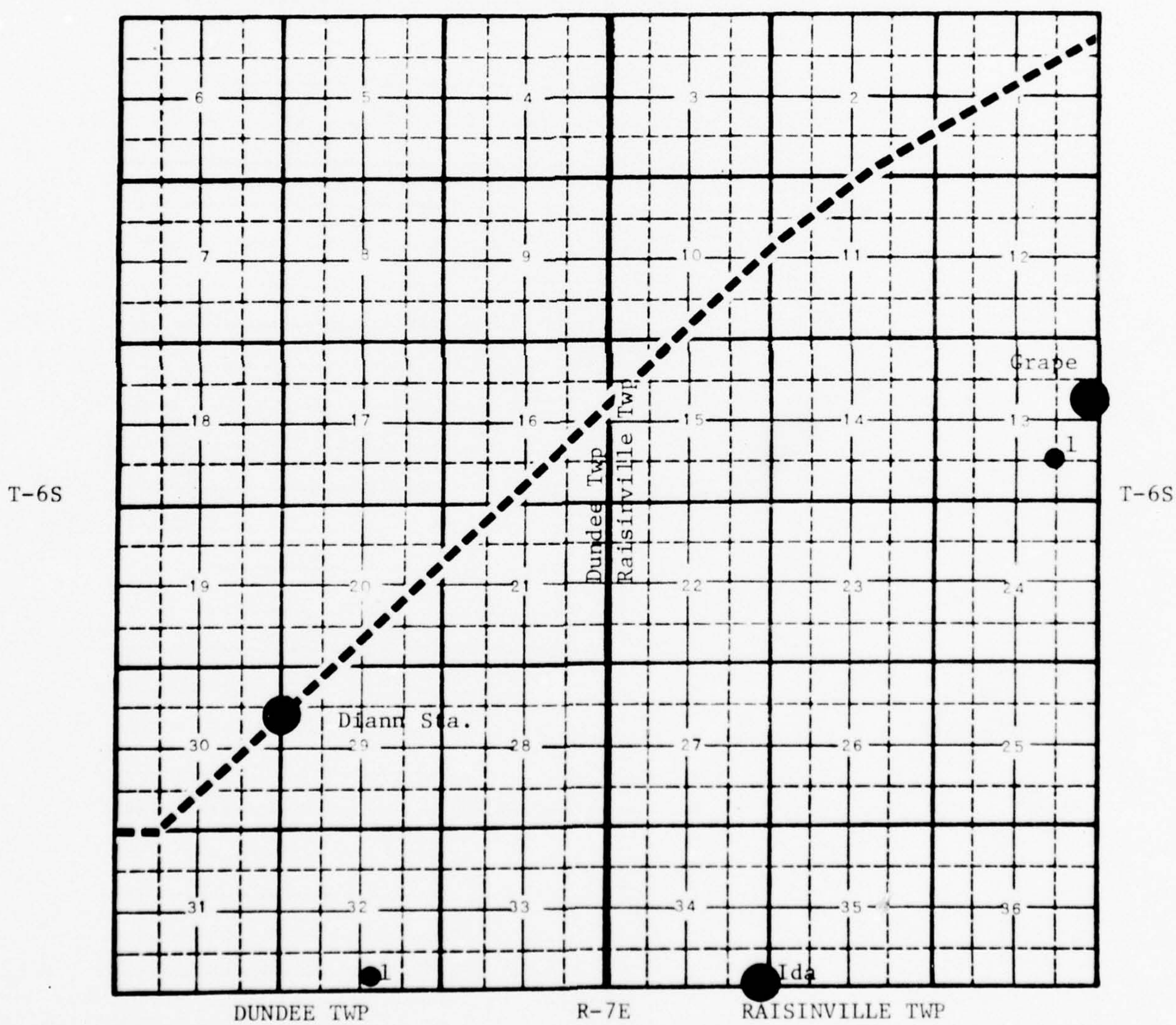


T-6S

RAISINVILLE TWP R-8E

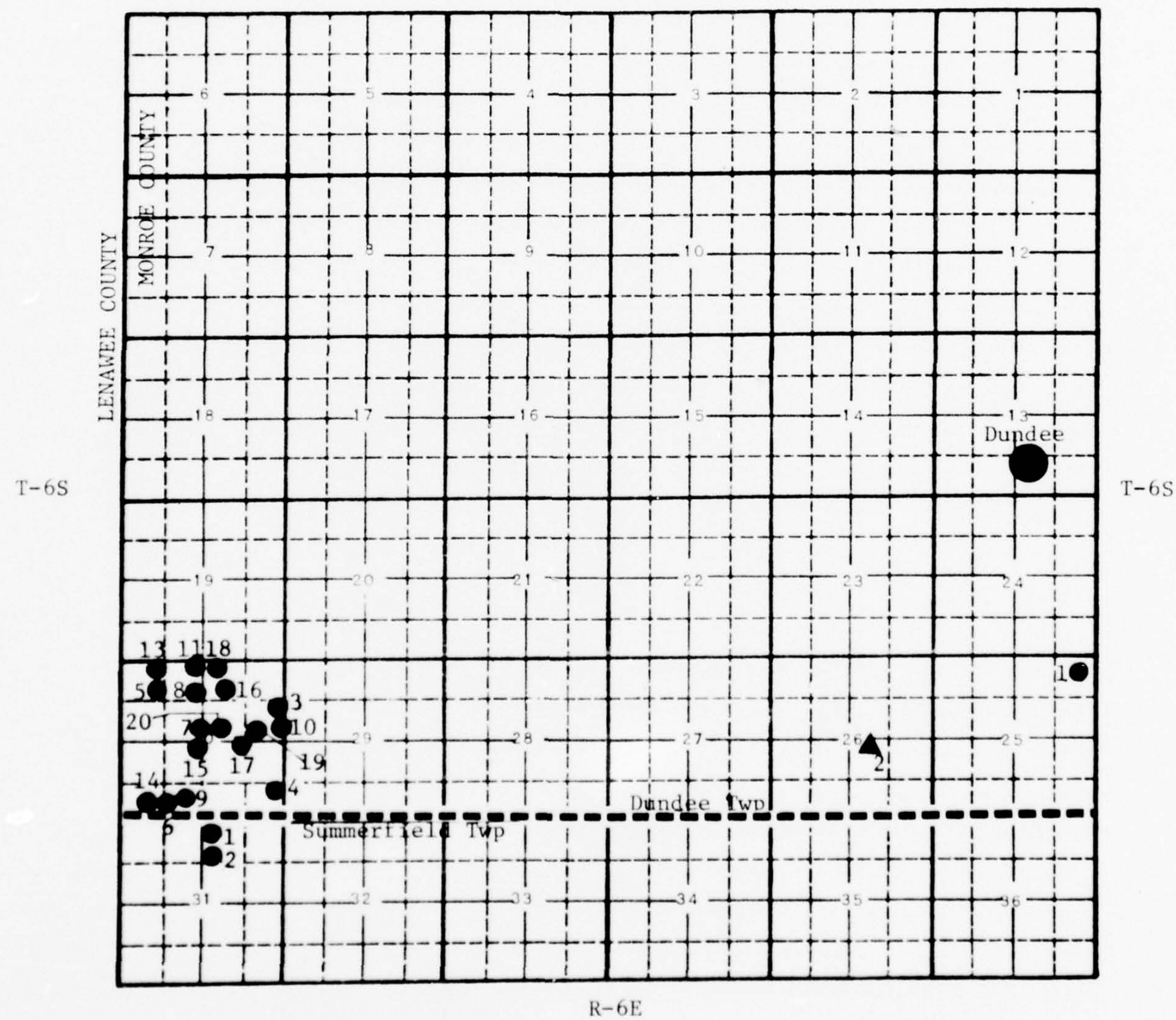
TOWNSHIP 6S **RANGE** 7E **COUNTY** MONROE **STATE** MICHIGAN

NOTES: MONROE COUNTY TO HILLSDALE COUNTY TUNNEL 4-13



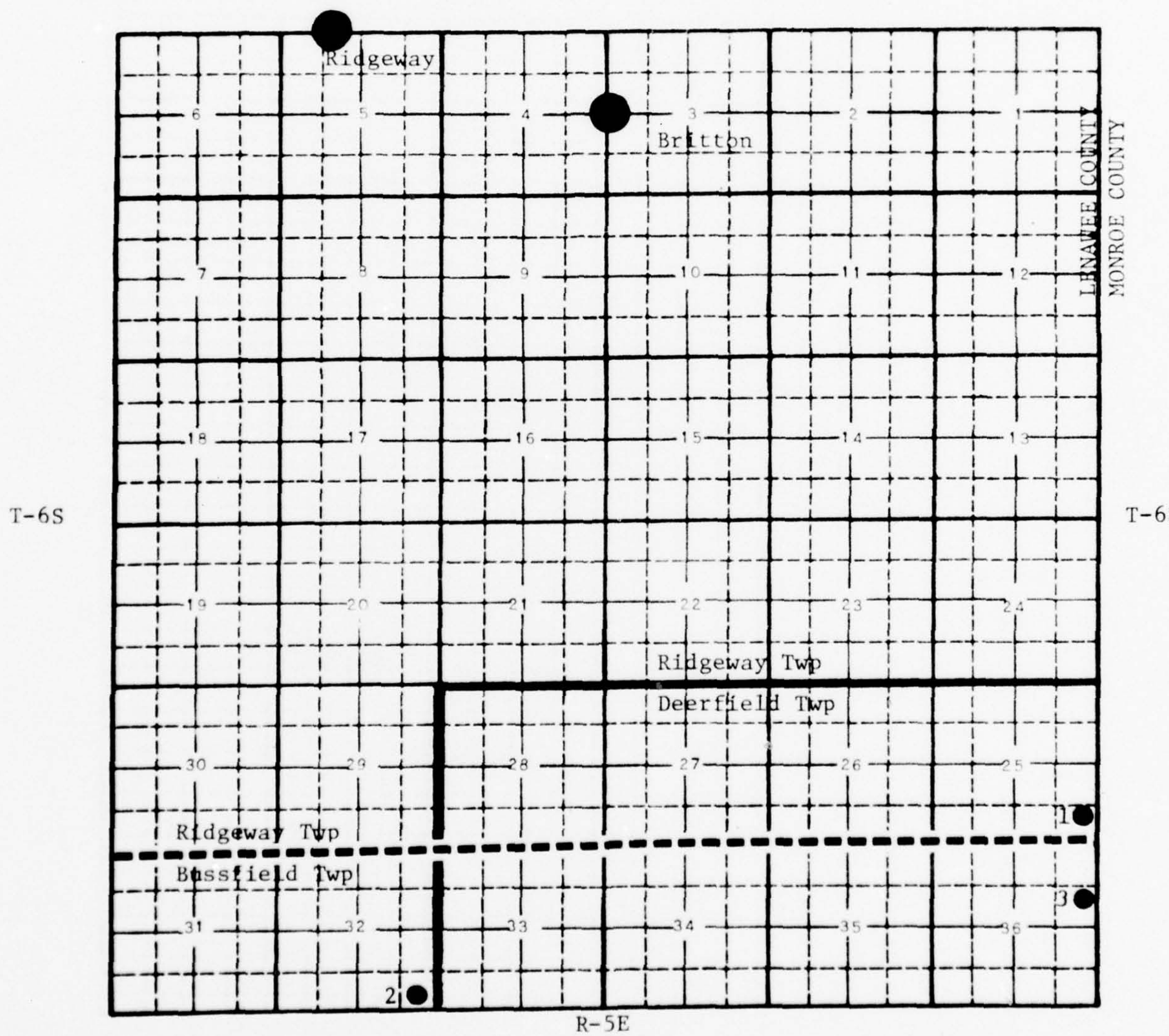
TOWNSHIP 6S RANGE 6E COUNTY MONROE STATE MICHIGAN

NOTES: MONROE COUNTY TO HILLSDALE COUNTY TUNNEL 5-13



TOWNSHIP 6S RANGE 5E COUNTY LENAWEE STATE MICHIGAN

NOTES: MONROE COUNTY TO HILLSDALE COUNTY TUNNEL 6-13

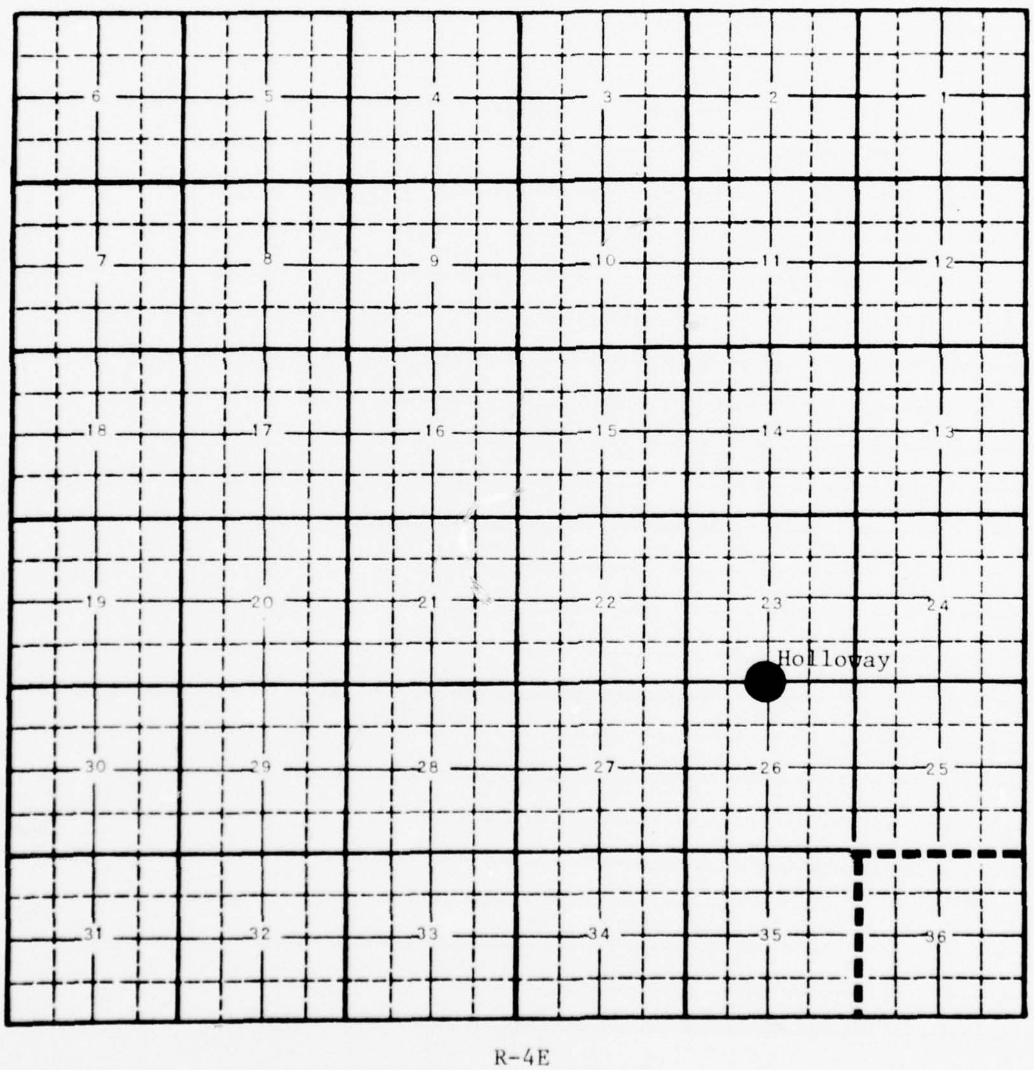


TOWNSHIP 6S RANGE 4E COUNTY LENAWEE STATE MICHIGAN

NOTES: MONROE COUNTY TO HILLSDALE COUNTY TUNNEL 7-13

NO RECORDS OF OIL & GAS WELL LOGS

T-6S



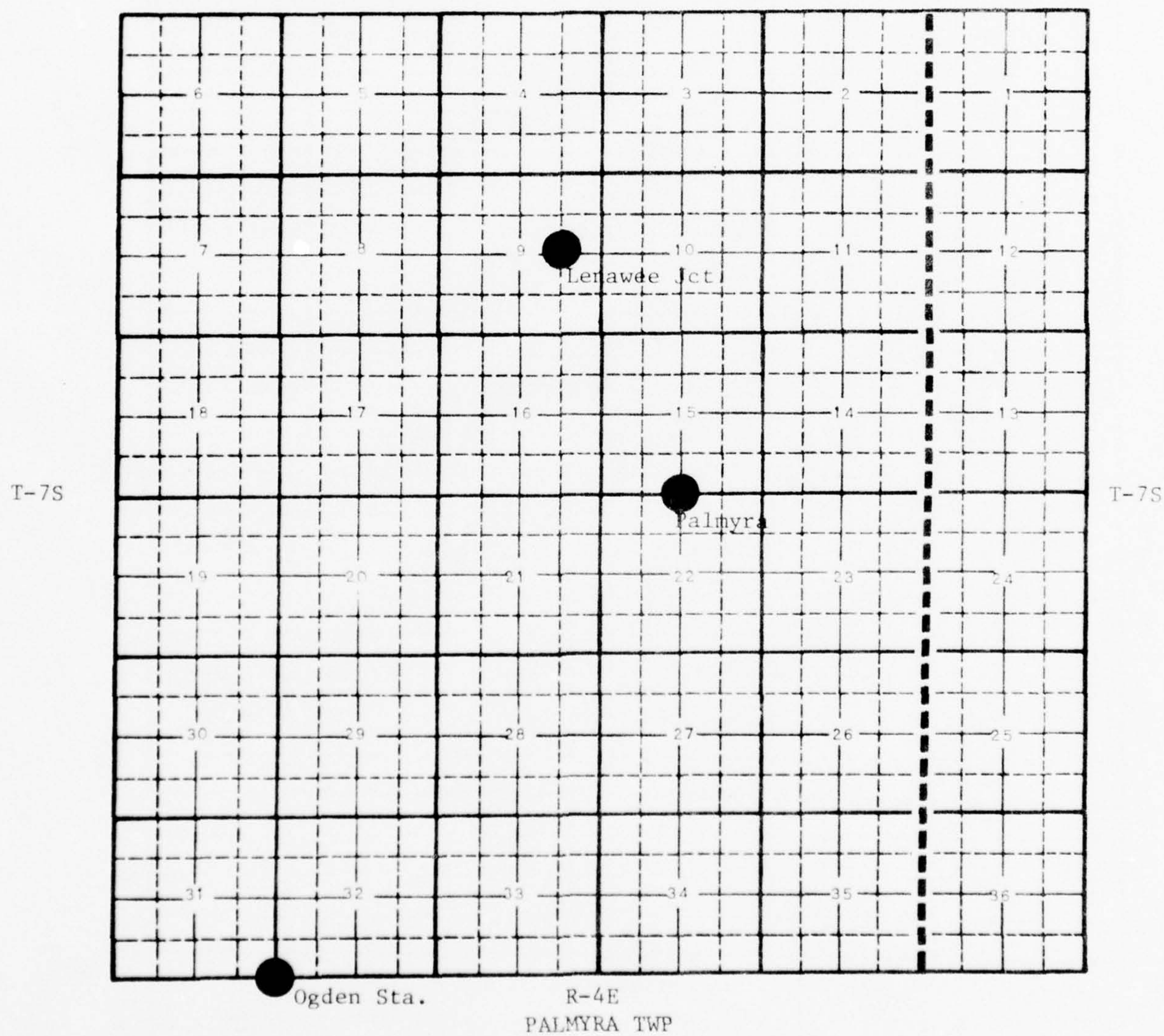
T-6S

R-4E
RAISIN TWP

TOWNSHIP 7S RANGE 4E COUNTY LENAWEE STATE MICHIGAN

NOTES: MONROE COUNTY TO HILLSDALE COUNTY TUNNEL 8-13

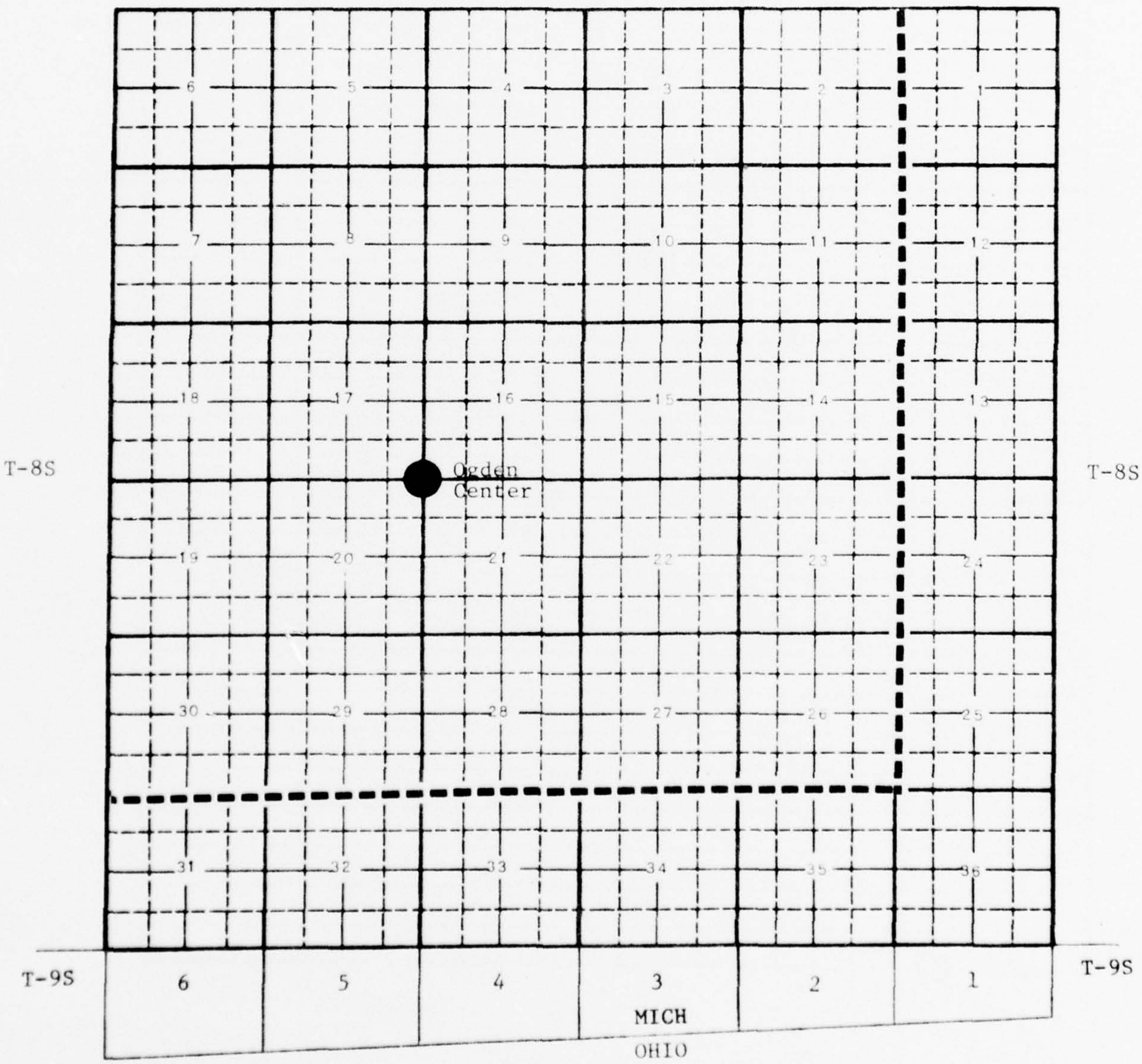
NO OIL & GAS WELL RECORDS



TOWNSHIP 8S-9S RANGE 4E COUNTY LENAWEE STATE MICHIGAN

NOTES: MONROE COUNTY TO HILLSDALE COUNTY TUNNEL 9-13

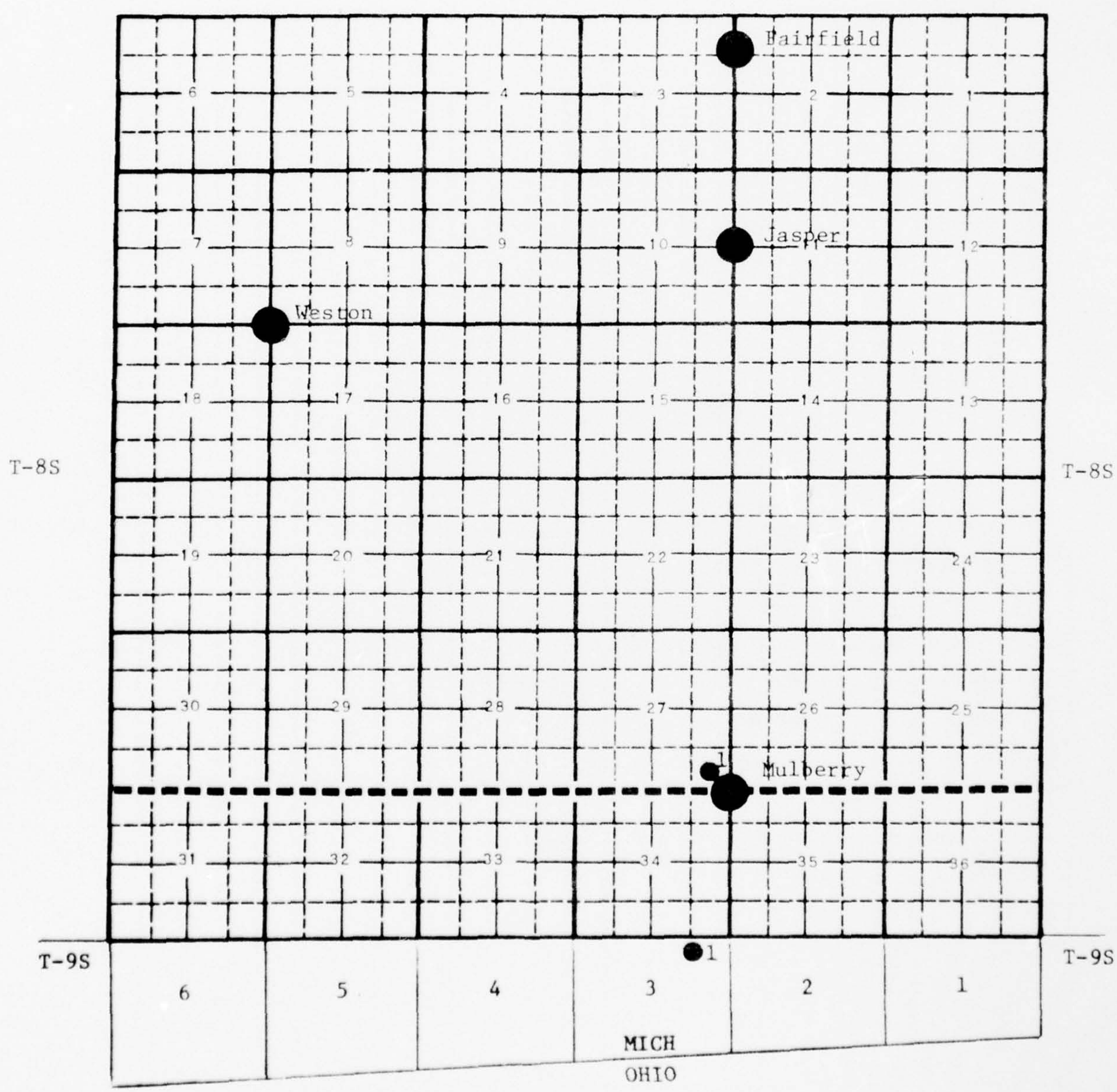
NO OIL & GAS WELL RECORDS



R-4E
OGDEN TWP

TOWNSHIP 8S-9S **RANGE** 3E **COUNTY** LENAWEE **STATE** MICHIGAN

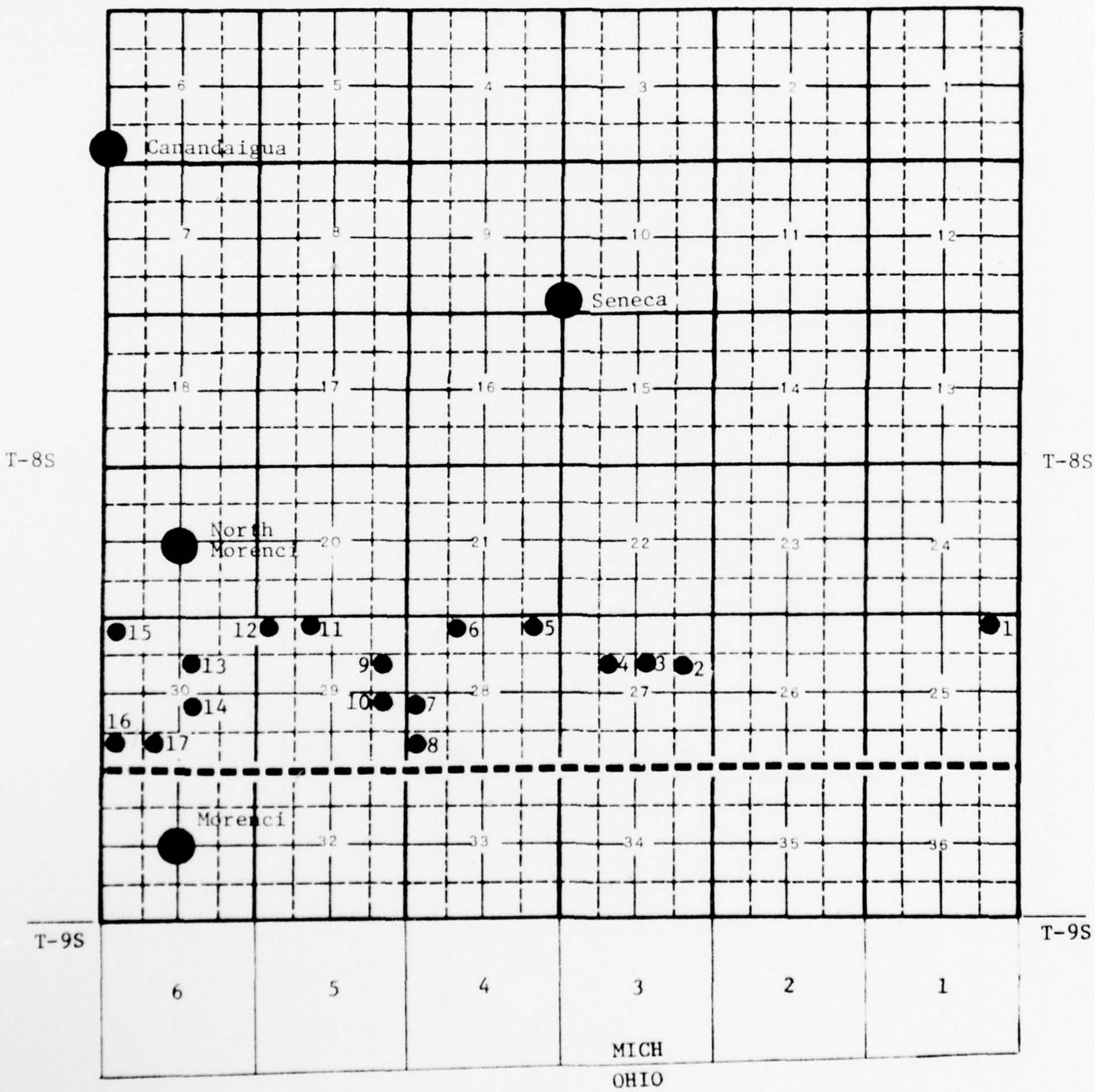
NOTES: MONROE COUNTY TO HILLSDALE COUNTY TUNNEL 10-13



R-3E
FAIRFIELD TWP

TOWNSHIP 8S-9S RANGE 2E COUNTY LENAWEE STATE MICHIGAN

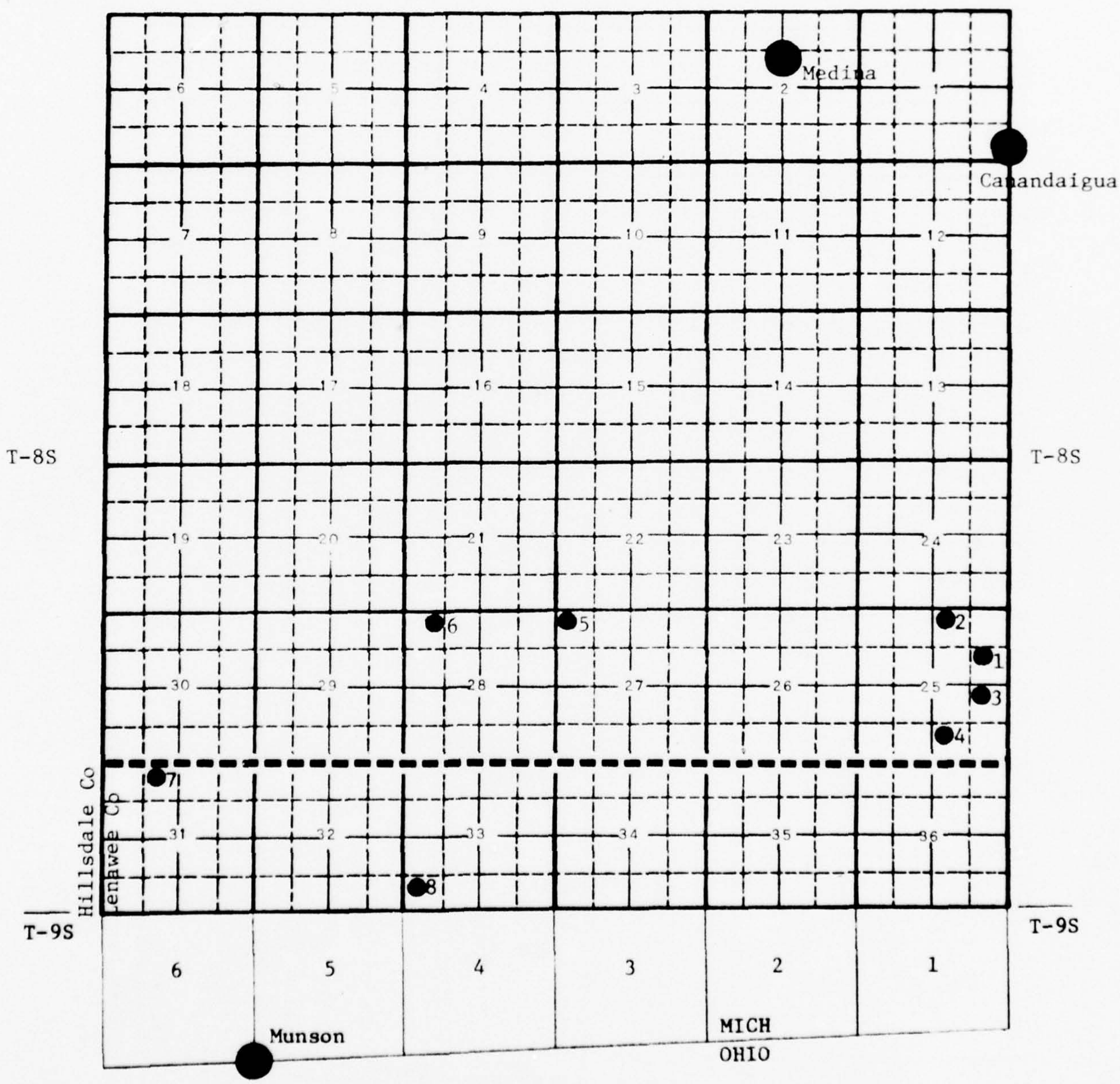
NOTES: MONROE COUNTY TO HILLSDALE COUNTY TUNNEL 11-13



R-2E
SENECA TWP

TOWNSHIP 8S **RANGE** 1E **COUNTY** LENAWEE **STATE** MICHIGAN

NOTES: MONROE COUNTY TO HILLSDALE COUNTY TUNNEL 12-13

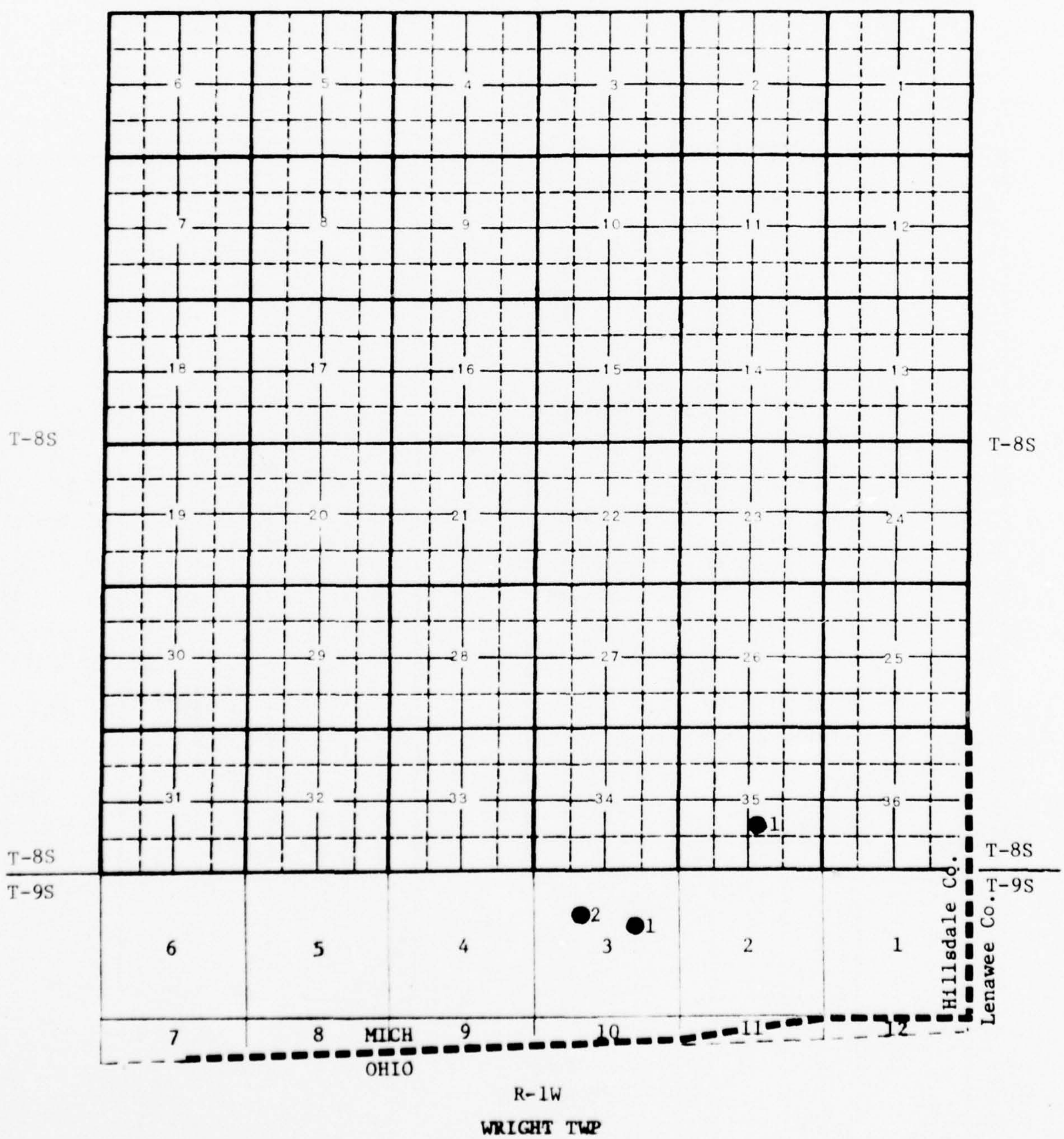


R-1E

MEDINA TWP

TOWNSHIP 8&9S RANGE 1W COUNTY HILLSDALE STATE MICHIGAN

NOTES: MONROE COUNTY TO HILLSDALE COUNTY TUNNEL 13-13



APPENDIX B

STORMWATER TUNNEL PROJECT -
PRELIMINARY
GEOLOGIC CONSIDERATIONS

ANDREW J. MOZOLA, PH D.

Consulting Geologist

SUBJECT: Storm Water Tunnel Project -- Preliminary Geologic Considerations.

TO : Mr. Robert Gregory, Chief Basin Planning Section, U. S. Army Engineer District, Detroit, P. O. Box 1027, Detroit, Michigan, 48231

DATE : June 2, 1972

Introduction

Michigan is a structural basin in which the sedimentary rocks of Paleozoic age dip inwardly from all directions toward the central area of the Southern Peninsula. The project area is situated along the southeast rim of this basin and, hence, the sedimentary strata have a general northeast-southwest strike with a gentle regional dip to the northwest. Except where local rock structures are involved, the regional dip is usually less than 40 feet per mile. The rock surface is dissected by numerous valleys of which some may exceed 200 feet in depth. The soil overburden will vary in thickness from less than 10 feet to more than 400 feet. Thickest overburden is usually found in those areas where morainic ridges cross or coincide with bedrock valleys.

Stratigraphy and Lithology

A review of the proposed storm water tunnels with respect to the geology of the southeastern Michigan area indicates that the following rock units will be encountered in the course of tunnel construction:

Coldwater Formation (youngest)	shale, some sandstone
Sunbury Formation	shale, dark brown to black
Berea Formation	sandstone, shale
Bedford Formation	shale
Antrim Formation	shale, dark brown to black
Traverse Group	shales, limestone, dolomite
Dundee Formation	limestone, some dolomite
Detroit River Group	
Anderdon Formation	limestone
Lucas Formation	dolomite
Amherstberg Formation	dolomite
Sylvania Formation	sandstone, dolomitic sandstone
Bois Blanc Formation	dolomite
Bass Islands Group	
Raisin River Formation	dolomite
Put-in-Bay Formation	dolomite
Salina Group (upper portion)	dolomite, shaly dolomite, shale.

With the exception of the Sylvania sandstone formation, it is to be noted that a carbonate lithology, with some shale horizons, dominates the

ANDREW J. MOZOLA, PH.D.
Consulting Geologist

sequence from the upper Salina upwardly through the Dundee formation. Carbonate rocks (limestones, dolomites as well as their shaly counterparts) are considered as being soluble and thus prone to solution by ground-water circulation particularly along bedding planes, joints, and fractures. Where solution has led to the development of subterranean caverns then sink hole features may occur on the bedrock surface.

The Traverse Group consists of a shale-carbonate lithology. This rock unit is usually not subdivided into distinct and separate formations in the subsurface of southeastern Michigan. The carbonate rocks can be thinly or massively bedded and, on occasion, rich in chert. The shale hori zons are generally blue-gray in color and may contain thin calcareous or dolomitic beds or lenses. The ratio of carbonate rock to shale within the total section of the Traverse Group can vary considerable from one area to another within the limits of the project area. Changes in ratio from place to place are usually gradual rather than abrupt.

Above the Traverse Group the remaining rock units constitute a clastic lithology principally shales, some sandstones (Berea Fm) with occasional lenses or layers of carbonate rock appearing in the sequence.

Potential Problems and Hazards

1. Solution enlarged joints, fractures, and bedding planes (subterranean passageways) in the carbonate rock sequence can function as conduits for ground-water movement. Hence, unexpected and copious volumes of ground-water may be encountered in the event these passageways are intersected in the course of tunneling. Should wells be required for dewatering purposes then another problem is generated in that the temporary lowering of the piezometric water level along the project route can result in the failure of nearby domestic wells. Continuous pumping to relieve the water problem during tunneling can bring about a change in the quality of the ground-water resulting in additional complaints from local residents. The occurrence of these subterranean passageways in the carbonate rock is difficult to predict without recourse to a program of closely spaced borings which may be prohibitive in terms of both time and cost. Rather than attempt to predict their presence perhaps provisions should be made to have the necessary equipment available to counter any excessive ground water discharge.

2. Hydrogen sulphide gas in association with ground-water is not unusual in the southeastern Michigan area. It is toxic and represents a hazard to personnel working in tight quarters such as narrow trenches, caissons, and tunnels without adequate ventilation.

ANDREW J. MOZOLA, Ph.D.
Consulting Geologist

3. As a general rule, ground-water discharge from the clastic rock sequence should not present any serious problems with respect to quantity except for highly weathered or fractured zones. However, the Antrim shale formation is known for its methane gas. This gas has also been detected in the soil overburden; its frequency of detection being greatest where the overburden rests directly over the outcrop area of the Antrim formation. With respect to the soil overburden the methane gas may be encountered (1) at any depth from the surface to the bedrock floor, (2) in any of the lithologies present in the soil overburden, (3) as free gas or mixed with ground-water, and (5) may occur as a slow unnoticeable seepage or as gas pockets with pressures reported as high as 37 pounds per square inch. In the Port Huron area methane gas encountered in the Antrim Formation had pressures up to 75 pounds per square inch.

Preliminary Comments Relating to the Proposed Tunnel Routes.

1. Port Huron to Algonac (St. Clair County): Soil overburden thickness 90 to 218 feet; bedrock surface elevations range from 375 to 525 feet above sea level (150+ feet relief); bedrock formations encountered predominantly clastic; methane gas in rock and soil overburden; artificial brine operations in the Marysville-Port Huron area.

2. Clinton River to Jefferson and thence along Jefferson to Monroe City: Soil overburden thickness 80-120 feet in Macomb County segment, 20-150 feet in Wayne County, 10-30 feet in Monroe County. Along this route the bedrock surface elevations range from 425 to 580 feet above sea level (155+ feet relief);bedrock formations -- mainly a carbonate lithology from the City of Monroe northward to Belle Isle in the City of Detroit, giving way to a shale-carbonate lithology (Traverse Group) for a short distance, and finally to a clastic lithology in northeast Wayne County and southeast Macomb County. Solution enlarged openings in the carbonate sequence are possible, particularly that portion of the proposed route in Macomb County. Methane gas also a hazard. Detroit Mine of the International Salt Company is located in the vicinity of the Rouge River and I-75 Freeway (depth 1100 ft); subsidence craters recently developed at northernmost end of Grosse Isle and presumably the result of brining operations; strong shows of ground water from wells penetrating Sylvania Formation in vicinity of Grosse Isle; possible artesian flowing well area in the City of Monroe and vicinity. Buried sink holes, brecciated rock possible along southernmost segment of this tunnel route.

3. Upper Rouge River -- Telegraph Road: Soil overburden 10-120 feet thick along Wayne County segment, 100-250 feet along Oakland County segment. Bedrock surface elevations range from 475 to 700 feet above sea level (225+ feet relief). Bedrock formations -- largely a carbonate lithology along southern one-third of proposed route, clastic lithology for remainder particularly in Oakland County. Methane gas can be expected in both

bedrock and soil overburden; solution enlarged openings in the carbonate section possible.

4. Six Mile Conner Creek Tunnel: Soil overburden 60-120 thick. Bedrock elevations range from 425 to 550 feet above sea level (125+ feet relief). Bedrock formations along route are largely clastics. The Antrim shale outcrops beneath the overburden along most of this route. Methane gas can be expected to be present.

5. River Rouge Tunnel: Soil overburden thickness from 50-150 feet. Bedrock eleveations 475-575 feet above sea level (100+ feet relief). In terms of bedrock units a clastic lithology prevails for the upper portion of the route and a carbonate lithology for the lower. Methane gas is to be expected.

Test Boring Program

1. Inasmuch as the bedrock surface is a hidden feature beneath the glacial overburden there is no assurance that the existing data (logs of oil and gas wells, water wells, and soil borings) include the highest and lowest possible bedrock elevations along each of the proposed tunnel routes. Hence, the indicated relief shown along each of the routes cannot be considered as maximum. Test boring program should include (1) detailed logging and sampling of both overburden and bedrock (slit spoon samples and cores, (2) geophysical logging of each hole for delineating water-bearing horizons, depth of rock weathering, and (3) testing for methane gas and hydrogen sulphide. To detect slow seepage of methane gas, it is recommended that each test hole, upon completion, should be capped for a period of 24-48 hours and then checked with an explosimeter.

2. Depending on the spacing and results of the test borings it may be advisable to complete the bedrock profile by geophysical survey methods.

3. Geological cross sections, based on existing data, along each of the proposed tunnel routes are currently under preparation.

Sincerely yours,

Andrew J. Mozola
2471 Mulberry Road
Bloomfield Hills, Michigan 48013

Tel: 335-6388

cc: Mr. Carr W. Baldwin, Ayres, Lewis, Norris, and May, Inc., Ann Arbor, Mich.

APPENDIX C

STORMWATER TUNNEL PROJECT -
BEDROCK SURFACE PROFILE
AND
GEOLOGIC STRUCTURE SECTIONS ALONG PROPOSED ROUTES

ANDREW J. MOZOLA, Ph.D.

Consulting Geologist

SUBJECT: Storm Water Tunnel Project -- Bedrock Surface Profile and Geologic Structure Sections Along Proposed Routes.

TO : Mr. Robert Gregory, Chief Basin Planning Section
U. S. Army Engineer District, Detroit, P. O. Box 1027
Detroit, Michigan 48231

DATE : July 29, 1972

1. Submitted herewith are the bedrock profiles and schematic geologic structures sections that have been added to the project drawings furnished by Ayres, Lewis, Norris and May, Inc.

2. The bedrock profile, bedrock topography and geologic cross sections are based on existing oil, gas and water well records and, to some extent, on soil test borings that have reached or penetrated bedrock. Of these various records only oil and gas logs provide usable information relative to bedrock lithology but unfortunately such records, except for St. Clair County, are sporadic in terms of areal distribution. From the drawings it will be evident that the density and distribution of control points for subsurface interpretation along the proposed routes leaves much to be desired.

3. Bedrock elevations and contours have been shown on both sides of the proposed routes for some distance in order to portray the configuration of the rock surface in terms of bedrock valleys and divides. Straight or gently curving contour lines imply a poor density and distribution of bedrock elevations; a higher density where they appear irregular in form. Contour interval is 25 feet except for that segment of the Jefferson Route in Monroe County.

4. The formation contacts shown in the structure cross sections are highly inferred and should not be used in determining the depth of any formation top or bottom along the proposed routes. As will be noted very few oil and gas records, when plotted, fell along the routes. As a general rule the various rock units increase in thickness to the northwest, i.e., in the direction of dip towards the center of the Michigan Basin. The variation in thickness of the rock units along the proposed routes is attributed to a combination of several factors namely (1) increase in thickness of the individual units towards the northwest, (2) effect of local rock structures, (3) local thickening of the units, (4) the direction of the route in relation to the regional strike and dip of the sedimentary strata and (5) the inherent difficulty in recognizing formation tops and bottoms in the subsurface. The dip of the strata along the proposed routes will vary depending upon the direction of the route in relation to the regional strike and dip and the presence of local structures. In any event, the strata are not as steeply inclined as shown since the cross sections represent a vertical exaggeration of 50x.

ANDREW J. MOZOLA, PH.D.

Consulting Geologist

5. Inasmuch as many of the rock units in this area have oil and gas producing horizons elsewhere in the State, occasional shows of oil and/or gas might be encountered in the course of tunneling, and hence the methane gas hazard is not restricted solely to the Antrim Shale.

6. Brief lithologic descriptions of the rock units and some unconfined compression test data of upper Traverse beds in the W 1/2, Sec. 26, T-1S, R-10E have been appended to this report. The latter represent tests on samples obtained from borings located one-half mile south of the intersection of Evergreen and Schoolcraft Roads where I-96 (Jeffries Freeway) crosses the C. and O. Railroad and Yard.

In the event there are some aspects of this report, or the prior report of June 2, 1972, that need further elucidation kindly do not hesitate to call upon me to do so.

Sincerely yours,

Andrew J. Mozola

Andrew J. Mozola
2471 Mulberry Road
Bloomfield Hills, Michigan 48013

Tel: (313) 335-6388

encl's: Lithologic descriptions
Unconfined compression test data

STRATIGRAPHIC SECTION IN SOUTHEASTERN MICHIGAN

Coldwater Formation

Youngest (uppermost stratigraphically) of the Paleozoic sedimentary strata to be encountered along the northernmost segment of the Upper Rouge River - Telegraph proposed tunnel. The total thickness of the Coldwater Formation in southeastern Michigan is approximately 850 feet. In all probability the proposed tunnel will penetrate the lower one-third to one-half of the total Coldwater section.

The formation is dominantly a blue, blue-gray to greenish gray, micaceous shale becoming more sandy and reddish in color in the upper part of the section. Some reddish, greenish, and purplish colored shale, though not of widespread extent, may be present near the base. Limestone, dolomite, sandstone, or siltstone as lenses, or as thin beds which are not continuous over large areas, may be interspersed with the shale. In some areas alternating shale and sandstone sequences appear but again subsurface records suggest that these are not of widespread areal occurrence. Clay-ironstone nodules are distinctive of the Coldwater. The nodules are small to fairly large concretionary masses characterized by an indurated clay, or silty clay, center and in turn surrounded by concentric limonitic shells. Both ball and pillow shaped clay-ironstones have been described from a Coldwater shale exposure in Branch County, Michigan. The former are usually spherical and average six inches in diameter; the latter are flattish and round with the largest one found measuring 42 inches in diameter.

The lower contact of the Coldwater Formation is easily recognized by the definite appearance of the dark brown to black shales of the underlying Sunbury Formation.

Some salt water and natural gas are known to be present in this formation as reported on the records of wells drilled in Holly and Independence townships in the northwestern and northern parts of Oakland County respectively. Reported yields of water wells completed in the Coldwater Formation ranged from 10 to 70 GPM depending on the depth of the well and, hence, the number of joints, fractures and bedding planes intersected (secondary permeability), or the number of sandstone and carbonate rock layers encountered. Some of the wells were flowing.

Sunbury Formation

A hard, dark brown, dark gray to black bituminous shale with traces of dolomite. Lithologically, it is similar in appearance to the Antrim Shale appearing lower in the stratigraphic sequence but lacking the abundance of fossil plant spore cases. Depending on geographic position the thickness of the Sunbury ranges from 20 to more than 50 feet. It appears that the formation thickens in the direction of dip. Presence of some natural gas in this unit is a distinct possibility.

The lower contact of this formation is usually place at first consistent appearance of the light-gray to blue shales, or the light-gray, fine-grained sandstones of the underlying Berea Formation.

Berea-Bedford Formations

Owing to the fact that the Berea-Bedford contact is difficult to recognize in the subsurface, the two formations are usually shown as a single unit on many geologic maps.

Berea Lithology: Fine-grained, white, gray to light drab to brown, micaceous sandstone in beds of varying thickness from 25 to 40 feet and nearly everywhere separated by beds of light-gray to blue gray shale having sporadic zones of calcareous or dolomitic material. The sandstone beds are usually well cemented but some friable zones, which are waterbearing, appear in the section. Thickness between 55 and 235 feet except where it outcrops beneath the soil overburden.

Bedford Lithology: Dominantly shale,in part calcareous and sandy. Generally light-gray in color with sporadic dark gray horizons. Occasional beds of micaceous sandstone, shaly dolomite, or limestone may appear in the section. Thickness 65 to 155 feet except in outcrop areas beneath the soil overburden.

The lower contact of the Bedford is usually placed at the first persistent appearance of the underlying dark brown to black Antrim Formation.

Natural gas is known to be present in the formation in other parts of the state. Gas show reported in exploratory oil and gas well in Independence Twp., Oakland County. Water wells penetrating the Berea have yields ranging from 5 to 30 GPM. Salt water is generally encountered in this formation where it is overlain by Sunbury and younger formations; potable water where the Berea occurs in outcrop beneath the soil overburden. Bedford formation not important as aquifer.

Antrim Formation

Predominantly a dark brown to black bituminous shale that is finely laminated and fissile so that the formation is frequently described by water well drillers as "black slate". Some gray shale may appear near the base. Pyrite and/or marcasite nodules present throughout the entire section. The lower portion is characterized by hard, black to dark brown, crystalline and nearly spherical concretions which are composed of the mineral "anthraconite", a petroliferous variety of calcium carbonate. These concretions often exceed 3 to 4 feet in diameter and may be mistakenly logged as limestone beds during drilling. An excellent outcrop revealing these nearly spherical concretions may be seen at Kettle Point, Ontario. Also characteristic of the Antrim Formation is the abundance of very small, but visible, disc-like resinous structures that are reddish-brown in color. These have been identified as fossil spore cases of floating fossil plants. Thickness in the southeastern Michigan area varies from 0 to nearly 200 feet.

The lower contact of the Antrim is uncertain because the basal gray shales, where present, resemble the blue-gray shales of the underlying Traverse Group.

Except for local areas where the formation is highly weathered, fractured, and overlain by the soil overburden, the Antrim is not important as an aquifer. The Antrim does contain methane gas and the formation, along with the overlying soil overburden, does constitute a hazard to construction projects.

Traverse Group

This group consists of limestones, shales and dolomites which are not subdivided into separate formations in the southeastern Michigan area. The shales are largely blue-gray to gray, occasionally brown, in color and may or may not contain thin calcareous or dolomitic beds or stringers. The carbonate rocks (limestone and dolomite) can be thinly or massively bedded and, in instances, are cherty. Generally the limestone beds are light gray, gray, or gray brown, fine to coarsely grained in texture and often high in calcium carbonate as to render them useful in Portland Cement making. At times, the limestone beds can be richly fossiliferous as to be called "shelly limestone" by drillers. The dolomite beds and their shaly counterparts are normally gray or buff in color, again thinly to massively bedded but somewhat more coarsely crystalline in texture. In the total section represented by the Traverse Group, the ratio or carbonate rocks to shale varies considerably from one area to another. Some logs of wells show a dominance of shale over carbonate materials; others the opposite situation. Pyrite is noted throughout the section. Thickness 0 to 300 feet.

The Traverse-Dundee contact is difficult to place in those areas where limestone beds of the Traverse Group rest directly on the Dundee limestone.

Occasional oil shows indicated on oil and gas logs. Limestone beds, if characterized by solution enlarged joints and fractures, can result in copious amounts of ground water. Hydrogen sulfide gas usually associated with the ground water.

It is to be noted that formations above the Traverse represent essentially a clastic sequence (shales-sandstones); below the Traverse, essentially a non-clastic, or carbonate, sequence (limestones-dolomites).

The base of the Traverse can be considered as marking the beginning of the carbonate rock sequence except for the Sylvania sandstone occurring lower in the section. Much of this carbonate sequence is represented along the proposed tunnel routes where it outcrops beneath the glacial soil overburden. From the Detroit area the thickness of the overburden decreases downriver towards Monroe, Michigan. The presence of solution enlarged openings in the carbonate sequence beneath the soil overburden should be expected and with it the probability of copious amounts of ground-water under artesian conditions, usually mineralized but potable, and characterized by an odor of hydrogen sulfide. Vintage geologic

reports make reference to flowing and non-flowing wells of high yield in the Rouge River Flats in Dearborn, in downtown Detroit and downriver towards Monroe, Michigan. Formations producing these high yields include the Dundee, Lucas, and Sylvania sandstones. The Swan Well (elevation of mouth, 597 feet A.S.L.) near the south end of Grosse Ile has been reported (1916) as having a depth of 2375 feet and flowing strongly (3000 GPM) since 1903. Strongest flows were encountered at depths of 420 feet (177 feet A.S.L.) and 450 feet (147 feet A.S.L.). Large springs were also reported to be common along the lower Huron River and Detroit River areas; specifically along the Huron River and also northward toward Gibralter and southward along the shore of Lake Erie in Monroe County. In fairly recent years strong flows of ground water occurred during caisson construction at the Northeast Water Filtration Plant (8 Mile Rd. and Van Dyke) and again at the site of New Quarry (Martin-Marietta) located in the southeasternmost extremity of Washtenaw County. The yield and quality of ground water (hydrogen sulfide) forced abandonment of quarry.

Dundee Formation

The formation consists of gray, bluish-gray, light buff to brown limestones, dolomitic limestones, and dolomites. The strata are thinly to massively bedded, finely to coarsely crystalline in texture, and containing cherty and/or siliceous horizons. Some shale horizons occasionally may be present in the section. The type locality of this formation is the old Christiancy Quarry at Dundee where it is a high-calcium limestone suitable for cement and lime. Although the Dundee is normally a limestone it is also a dolomitic limestone or dolomitic elsewhere within its outcrop area. Carbonaceous partings between limestone beds and cavities containing hydrocarbons are common. Grains of frosted quartz sand appear abundant in the basal beds. Thickness 0 to 160 feet.

The lower contact of the Dundee is difficult to place in the subsurface in that the underlying Detroit River Group consists of limestones and dolomites.

Detroit River Group

This group where exposed in quarries in Monroe County and northwestern Ohio has been subdivided, in descending order, into the Anderdon (24 feet), Lucas (84 feet), Amherstburg (19 feet), and Sylvania (50 feet) formations. These increase in thickness towards the north and northwest. The uppermost three formations consist predominantly of a carbonate lithology that is difficult to differentiate, in terms of their contacts, in the subsurface. The Sylvania Formation is a quartz rich sandstone and easily recognized. For this reason the Detroit River Group is shown on geologic maps as two separate units--a non-clastic unit designated as the Detroit River Dolomites (Anderdon, Lucas, Amherstburg) and the clastic unit as the Sylvania Sandstone.

Detroit River Dolomite Lithology

The Anderdon, uppermost of the group, consists of a high calcium limestone which makes it difficult to distinguish from the overlying Dundee Limestone. Dolomite beds, however can be expected within the Anderdon in some areas. The remaining (Lucas, Amherstburg) are nominally dolomites with some limestone beds, occasionally cherty and/or argillaceous. These dolomites vary in color--gray, buff, light brown, light gray to white and have textures ranging from finely crystalline to granular. Irregular cavities (vugs) are common and frequently lined with calcite crystals measuring 3-4 inches in length in a form known as "dog-tooth spar". Occasional masses and crystals of native sulfur are not uncommon. Anhydrite ($CaSO_4$) can be present, particularly in the Lucas Formation, as thin beds of limited areal extent or as lenses. As the basal beds of the Amherstburg are approached there is an increase in the amount of frosted quartz sand grains similar in appearance to the quartz sand which makes up the underlying Sylvania Sandstone.

The lower contact of the Detroit River Group is usually placed at the first persistent appearance of sandstone of the underlying Sylvania Formation

Sylvania Formation Lithology

A white to light gray, fine to medium grained, high-purity quartz sandstone. Individual grains are frosted in appearance, subangular to rounded in shape. The sandstone is poorly cemented and becomes extremely friable upon exposure to weathering. When crushed, screened and washed the sand resembles granular sugar; terms such as "sugar sand" and "silica sand" are common notations in driller's records. Where the Sylvania has been exposed to weathering, a dull gray appearance predominates in contrast to a nearly pure white color when freshly quarried. Paper thin seams of carbonaceous materials are very apparent on fresh cuts and occur at varying intervals. Geodes (cavities) lined with calcite and/or celestite crystals are common; on rare occasions native sulfur may be found. Near the base of the formation 15 to 20 feet of sandy dolomite is usually encountered which is light to dark gray in color and containing some zones of chert nodules and dolomite pebbles. In Monroe County the basal beds of this formation rest unconformably (prior erosion surface) on the Bois Blanc Formation or the Bass Islands Group. In Ohio, pebbles derived from the upper Bass Islands beds have been incorporated in the basal Sylvania beds. The Sylvania thickens to the west and north. Thickness in southeast Michigan is 0 to 288 feet.

Lower contact may rest on Bois Blanc Formation or the Bass Islands Group of dolomites.

Good aquifer. Many domestic wells are completed in the Sylvania sandstone in its outcrop area in Monroe County. If project requires dewatering in the course of tunneling in Monroe County then domestic well failures, or decreased well performance, may be expected.

Though the quartz sand grains are highly abrasive, the Sylvania sandstone is considered to be poorly cemented. Low unconfined compressive strengths may be characteristic of this sandstone.

Bois Blanc Formation

Not shown as a rock unit on geologic maps of the southeastern Michigan area because of the difficulty in recognizing its boundaries and correlating between areas due to scarcity of records. Both the upper and lower contacts of the Bois Blanc are marked by erosional unconformities and, therefore, its thickness can vary considerably from place to place. Though reported as eroded in southern Michigan and northern Ohio, its removal was not necessarily complete everywhere in the region. Remnants of the Bois Blanc in the project area beneath the drift are possible and, if recognized, are most likely to occur on the bedrock surface highs.

Lithology: The Bois Blanc Formation has a lithology dominated by dolomites though in some areas limestones may prevail. The dolomites are light gray to gray-brown, tan to light brown or medium brown in color, and characterized by fine to medium-grained textures. Chert is abundant throughout the section and, perhaps, represents a useful criterion for the recognition of the Bois Blanc in the subsurface. Some horizons have been reported as chert-rich (up to 20 percent) which may imply weathering particularly if the chert itself shows signs of decomposition and staining by iron oxides. The chert is highly variable; it can be hard (unweathered) or soft (weathered), smooth, occasionally vitreous, and frequently features conchoidal fractures. Color may be white, light to dark gray, brownish-gray, or bluish-gray. Siliceous zones or cherty streaks within dolomite and limestone beds are also present.

Thickness of the Bois Blanc varies from 0 to 125 feet and is highly variable within short distances laterally.

Bass Islands Group

Lithology: Includes the Raisin River and Put-In Bay dolomites which are usually not dubdivided in the subsurface. The group consists largely of light gray, tan, buff, brown, or dark brown, dense to finely crystalline dolomites and shaly dolomites. In some areas dense to finely crystalline limestone may prevail. Vugs, tiny fractures, and highly porous zones may be locally characteristic. Gypsum and anhydrite in thin beds, as nodules or stringers, as well as clear selenite occur more commonly in the Bass Islands than in the overlying rock units.

Thickness 0 to 302 feet. Lower contact not easily recognized.

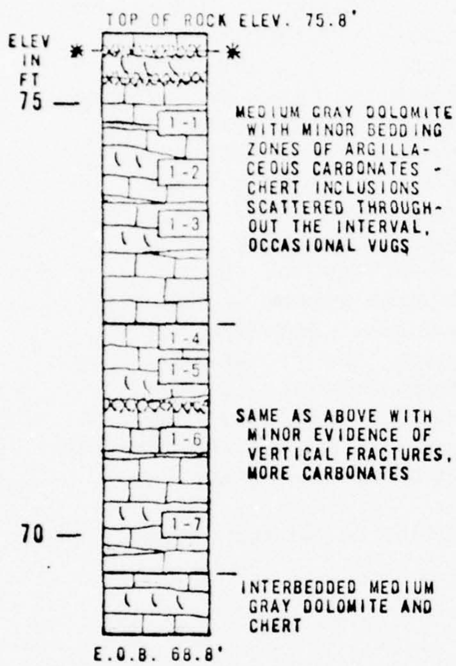
Salina Group

In the Monroe County area the Salina Group consists largely of dolomites and shaly dolomites with appreciable amounts of dolomitic shale,

and alternating shale-dolomite sequences, particularly in the upper portion. The dolomites are gray, buff, light brown, or brown in color, dense to finely crystalline in texture but occasionally coarse. Anhydrite and gypsum are commonly associated with the dolomite but salt beds are rarely present. The dolomites are further characterized by stylolitic seams, black shale or carbonaceous partings, vugs, crevices, porous zones and, in some instances, cavernous. Hydrocarbons (often as black oil in pores), petroliferous odors and shows of gas are not unusual. The shale beds are usually gray, but green, greenish-gray, and minor amounts of red may be present. The shale beds may contain dolomitic beds or stringers, gypsum, anhydrite, and occasional oil and gas shows. Anhydrite may appear in the section as distinct beds 5 to 15 feet with stringers, or inclusions, of shale and/or dolomitic shale. Within the total Salina Section gypsum is usually massive, white, and in thin beds, stringers, and nodules. Selenite and satin spar varieties of gypsum, though minor in amount, are frequently noted in oil and gas logs. The most distinctive characteristic of the Salina Group in Monroe County is the apparent absence of salt beds (only one instance of a 5 foot bed) which is in marked contrast to the considerable aggregate thickness of salt (730 feet) in Wayne County to the north.

Thickness 0 to 820 feet. Oldest of the rock units to be encountered along the proposed tunnel routes.

LOG OF ROCK PROFILE



—— Water return loss

xxxxxxxx Fracture Zone

SAMPLE NO.	ELEV IN FEET	DRY BULK SP GRAV	POROSITY %	UNCONFINED COMPRESSION TEST DATA: UNCONFINED COMPRESSIVE STRENGTH, PSI	DEFORMATION AT FAILURE, %	TANGENT MODULUS AT 50% ULTIMATE STRENGTH, PSI	L/D RATIO
1-1	74.7	2.80	1.26	25,280	.41	5.88×10^6	2.07
1-2	74.1	2.78	1.92	23,940	.63	4.30×10^6	1.92
1-3	73.5	2.71	4.46	9,110	.47	2.05×10^6	2.05
1-4	72.2	2.63	5.32	7,430	.53	1.12×10^6	2.05
1-5	71.8	2.76	2.53	11,330	.29	3.86×10^6	2.09
1-6	71.0	2.75	2.07	18,690	.52	3.86×10^6	2.10
1-7	70.0	2.72	3.73	17,300	.41	4.98×10^6	2.10

WATER LEVEL IN CASING: Not recorded
RECOVERY: 100%
39% based on cores 4" or longer

BORING DATA:

NUMBER: RCB-1
DATE OF BORING: October, 1971
LOCATION: Sta 238+00, 134'Rt of Construction ℄
GROUND ELEVATION: 146.3 ft
MADE BY: J. P. McGuire, Geophysical Unit
GEOLOGICAL LOGS BY: Geophysical Unit Geologists

Project 82122
PROPOSED I-96 (JEFFRIES FWY) THROUGH
OAK YARD, CITY OF DETROIT
WAYNE COUNTY, MICHIGAN

W 1/2, Sec 26, T-1S-R10E
I-96 over C&O RR (OAK YD)

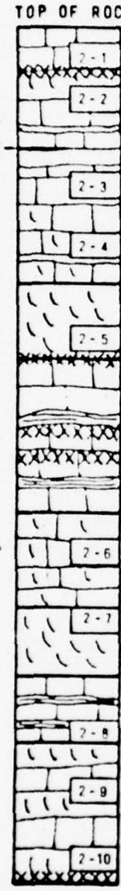
LOG OF ROCK PROFILE

TOP OF ROCK ELEV 71.1

ELEV IN FEET

70 —

65 —



MEDIUM GRAY DOLOMITE WITH MINOR BEDDING ZONES OF ARGILLACEOUS CARBONATES - CHERT INCLUSIONS SCATTERED THROUGHOUT THE INTERVAL, OCCASIONAL VUGS

GRAY BANDED CHERT - SOME EVIDENCE OF VERTICAL FRACTURES

MEDIUM GRAY DOLOMITE WITH SHALE PARTINGS, VERY MINOR VERTICAL FRACTURES

GRAY CHERTY DOLOMITE

GRAY CHERT

PETROLIFEROUS MEDIUM GRAY DOLOMITE WITH SHALY ZONES, SOME PARTINGS - SOME VUGS IN DOLOMITE

INTERBEDDED GRAY AND WHITE CHERTS AND MEDIUM GRAY DOLOMITE

E.O.B. 61.1

XXXXXXXX Fracture Zone

—— Water return loss

SAMPLE NO.	ELEV IN FEET	DRY BULK SP GRAV	POROSITY %	UNCONFINED COMPRESSION TEST DATA			
				UNCONFINED COMPRESSIVE STRENGTH, PSI	DEFORMATION AT FAILURE, %	TANGENT MODULUS AT 50% ULTIMATE STRENGTH, PSI	L/D RATIO
2-1	70.8	2.75	3.02	13,180	.41	3.29×10^6	2.05
2-2	70.2	2.77	1.93	15,610	.48	3.90×10^6	2.04
2-3	69.2	2.63	6.64	9,760	.30	3.60×10^6	2.02
2-4	68.5	2.77	2.20	19,160	.36	9.08×10^6	2.02
2-5	67.4	2.59	0.64	NO TEST			
2-6	64.9	2.80	1.94	12,560	.42	2.84×10^6	2.02
2-7	64.1	2.71	2.91	16,900	.48	4.67×10^6	2.02
2-8	62.8	2.66	6.05	5,960	.36	1.78×10^6	1.36
2-9	62.1	2.66	4.77	17,990	.30	8.01×10^6	2.01
2-10	61.3	2.28	15.66	3,500	.18	1.67×10^6	2.00

WATER LEVEL IN CASING: Not recorded
RECOVERY: 100%
47% based on cores 4" or longer (52% 1st 5', 42% 2nd 5')

BORING DATA:

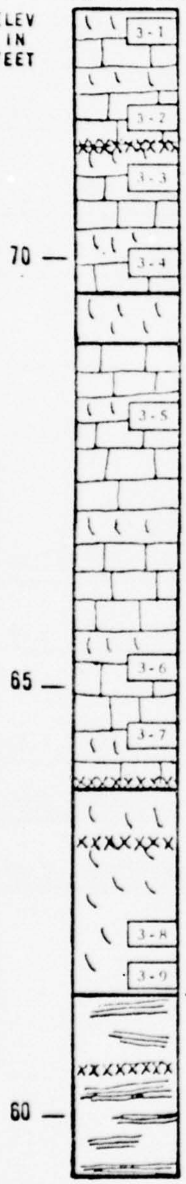
NUMBER: RCB-2
DATE OF BORING: October, 1971
LOCATION: Sta 239+40, 177'Lt of Construction ₵
GROUND ELEVATION: 146.7 ft
MADE BY: J. P. McGuire, Geophysical Unit
GEOLOGICAL LOGS BY: Geophysical Unit Geologists

Project 82122
PROPOSED I-96 (JEFFRIES FWY) THROUGH
OAK YARD, CITY OF DETROIT
WAYNE COUNTY, MICHIGAN

LOG OF ROCK PROFILE

TOP OF ROCK ELEV 72.9

ELEV IN FEET



MEDIUM GRAY PETROLIFEROUS VUGGY DOLOMITE WITH MANY CHERT ZONES - SOLID CHERT ZONES FROM 69.6' to 69.0' and 63.8' to 61.4'

BUFF ARGILLACEOUS SILTSTONE AND SHALES INTERBEDDED

E.O.B. 59.3'

xxxxxxxx Fracture Zone

SAMPLE NO.	ELEV IN FEET	DRY BULK SP GRAV	POROSITY %	UNCONFINED COMPRESSION TEST DATA: UNCONFINED COMPRESSIVE STRENGTH, PSI	DEFORMATION AT FAILURE, %	TANGENT MODULUS AT 50% ULTIMATE STRENGTH, PSI	L/D RATIO
3-1	72.6	2.79	1.54	18,820	.23	3.63×10^6	2.09
3-2	71.6	2.75	1.85	18,250	.63	2.71×10^6	2.13
3-3	70.9	2.66	5.90	8,290	.28	3.21×10^6	2.15
3-4	69.9	2.57	3.28	10,430	.28	3.23×10^6	2.16
3-5	68.1	2.72	2.76	15,880	.62	--	2.18
3-6	65.2	2.44	7.36	14,080	.52	4.81×10^6	2.09
3-7	64.4	2.72	3.90	10,180	.06	--	1.91
3-8	62.1	2.57	9.09	7,540	.18	2.18×10^6	2.09
3-9	61.6	2.56	8.90	7,910	.34	3.03×10^6	2.16

WATER RETURN LOSS: Intermittent
WATER LEVEL IN CASING: Elev 98.9'
RECOVERY: 92%

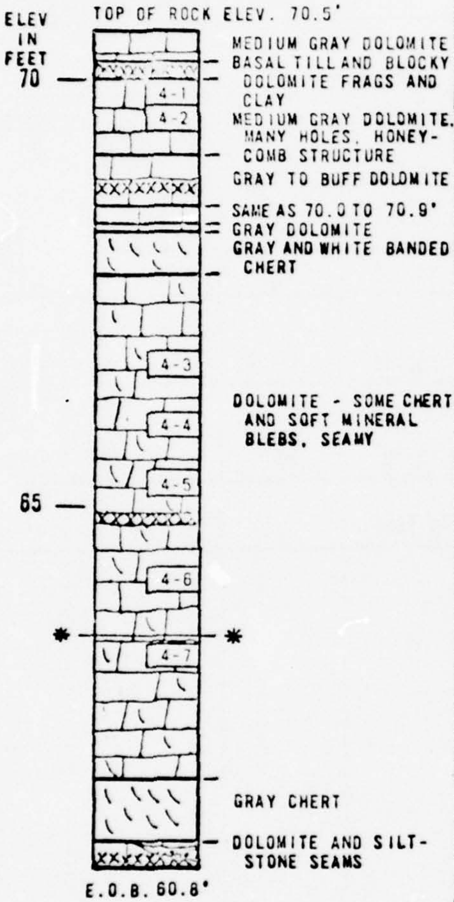
BORING DATA:

NUMBER: RCB-3
DATE OF BORING: October, 1971
LOCATION: Sta 241+35, 120'Rt of Construction ₵
GROUND ELEVATION: 146.4 ft
MADE BY: J. P. McGuire, Geophysical Unit
GEOLOGICAL LOGS BY: Geophysical Unit Geologists

Project 82122

PROPOSED I-96 (JEFFRIES FWY) THROU
OAK YARD, CITY OF DETROIT
WAYNE COUNTY, MICHIGAN

LOG OF ROCK PROFILE



SAMPLE NO.	ELEV IN FEET	DRY BULK SP GRAV	POROS-ITY %	UNCONFINED COMPRESSION TEST DATA			
				UNCONFINED COMPRES-SIVE STRENGTH, PSI	DEFORMA-TION AT FAILURE, %	TANGENT MODULUS AT 50% ULTIMATE STRENGTH, PSI	L/D RATIO
4-1	69.9	2.52	10.78	8,270	.30	4.14×10^6	1.64
4-2	69.5	2.52	11.01	10,930	.28	3.58×10^6	2.10
4-3	66.7	2.74	3.25	7,570	.17	3.75×10^6	2.10
4-4	66.0	2.71	3.97	2,900	.15	1.68×10^6	2.07
4-5	65.3	2.73	3.81	12,990	.46	2.99×10^6	2.11
4-6	64.1	2.79	1.41	19,910	.29	5.87×10^6	2.10
4-7	63.3	2.75	2.77	13,500	.47	3.64×10^6	2.08

——— Water return loss

xxxxxxxx Fracture Zone

WATER LEVEL IN CASING: Elev 98.5'
RECOVERY: 97%
33% based on cores 4" or longer (27% 1st 5', 40% 2nd 4.7')

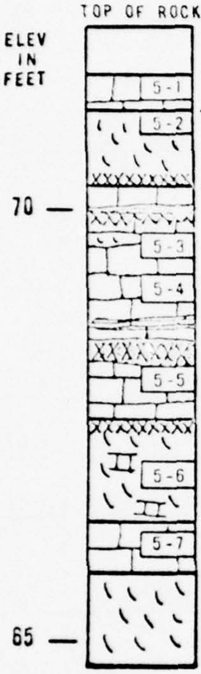
BORING DATA:

NUMBER: RCB-4
DATE OF BORING: October, 1971
LOCATION: Sta 243+00, 166'Lt of Construction ℄
GROUND ELEVATION: 144.5 ft
MADE BY: J. P. McGuire, Geophysical Unit
GEOLOGICAL LOGS BY: Geophysical Unit Geologists

Project 82122
PROPOSED I-96 (JEFFRIES FWY) THROUGH OAK YARD, CITY OF DETROIT WAYNE COUNTY, MICHIGAN

LOG OF ROCK PROFILE

TOP OF ROCK ELEV 72.1'



NOT RECORDED, HOLE CLEANED WITH CHOPPING BIT

GRAY DOLOMITE

LIGHT GRAY CHERT

GRAY DOLOMITE - MANY CHERT SEAMS AND NODULES, SOME SHALY APPEARING SEAMS THROUGHOUT THE INTERVAL - 68.5' TO 68.2' BROKEN ROCK, ARENACEOUS

GRAY AND WHITE CHERT, SOME DOLOMITE - SOME PARTINGS

GRAY DOLOMITE - CHERT NODULES - SEAMY

GRAY AND WHITE MOTTLED CHERT - HARD

E.O.B. 64.7'

xxxxxxxx Fracture Zone

SAMPLE NO.	ELEV IN FEET	DRY BULK SP GRAV	POROSITY %	UNCONFINED COMPRESSION TEST DATA: UNCONFINED COMPRESSIVE STRENGTH, PSI	DEFORMATION AT FAILURE, %	TANGENT MODULUS AT 50% ULTIMATE STRENGTH, PSI	L/D RATIO
5-1	71.4	2.74	3.27	16,840	.50	3.58×10^6	1.81
5-2	71.0	2.56	3.30	3,930	.18	--	2.04
5-3	69.6	2.76	1.86	16,260	.30	4.85×10^6	2.03
5-4	69.1	2.73	2.93	13,210	.45	4.13×10^6	1.87
5-5	68.0	2.75	2.39	10,140	.17	--	2.08
5-6	67.0	2.61	3.88	13,080	.35	4.14×10^6	2.08
5-7	66.1	2.78	2.25	NO TEST		--	--

WATER LEVEL IN CASING: Not recorded
RECOVERY: Nearly 100%
30% based on cores 4" or longer (32% 1st 5', 24% 2nd 1.8')

BORING DATA:
NUMBER: RCB-5
DATE OF BORING: October, 1971
LOCATION: Sta 245+00, 124'Rt of Construction ℄
GROUND ELEVATION: 145.6 ft
MADE BY: J. P. McGuire, Geophysical Unit
GEOLOGICAL LOGS BY: Geophysical Unit Geologists

Project 82122
PROPOSED I-96 (JEFFRIES FWY) THROUGH
OAK YARD, CITY OF DETROIT
WAYNE COUNTY, MICHIGAN

LOG OF ROCK PROFILE

TOP OF ROCK ELEV 72.0'

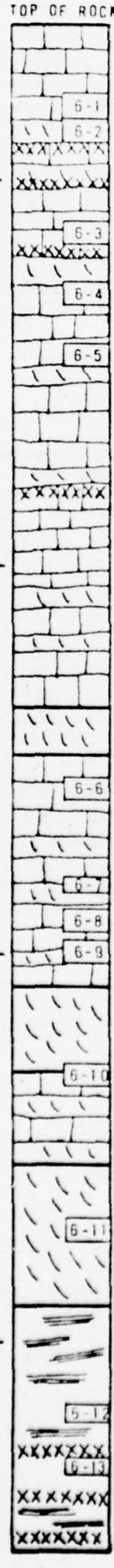
ELEV IN FEET

70 —

65 —

60 —

55 —



MEDIUM GRAY DOLOMITE WITH MINOR BEDDING ZONES OF ARGILLACEOUS CARBONATES - CHERT INCLUSIONS SCATTERED THROUGHOUT THE INTERVAL - OCCASIONAL VUGS

GRAY BANDED CHERT

MEDIUM GRAY DOLOMITE WITH MANY CHERT ZONES SIMILAR TO 72.0' TO 63.2'

GRAY AND WHITE MOTTLED CHERT

LIKE 72.0' TO 63.2', HIGHLY VUGGY

GRAY AND WHITE MOTTLED CHERT

BUFF ARGILLACEOUS SILTSTONE - SHALY

E.O.B. 52.3'

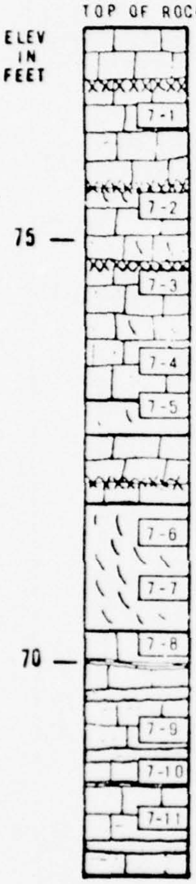
RCB#6

SAMPLE NO.	ELEV IN FEET	DRY BULK SP GRAV	POROSITY %	UNCONFINED COMPRESSION TEST DATA: UNCONFINED COMPRESSIVE STRENGTH, PSI	DEFORMATION AT FAILURE, %	TANGENT MODULUS AT 50% ULTIMATE STRENGTH, PSI	L/D RATIO
6-1	70.9	2.59	8.68	13,410	.23	6.03×10^6	2.08
6-2	70.6	2.52	10.62	11,470	.24	4.73×10^6	2.05
6-3	69.3	2.67	3.49	16,560	.58	5.12×10^6	1.48
6-4	68.5	2.77	2.18	9,860	.11	9.35×10^6	2.12
6-5	67.7	2.77	2.07	11,120	.45	1.59×10^6	1.63
6-6	62.1	2.78	0.29	26,040	.53	5.29×10^6	1.83
6-7	60.9	2.62	6.66	3,730	.12	--	1.97
6-8	60.4	2.74	2.54	6,770	.30	2.35×10^6	2.04
6-9	60.0	2.78	1.85	10,930	.31	3.33×10^6	1.97
6-10	58.4	2.41	8.04	7,430	.29	2.56×10^6	2.08
6-11	56.4	2.40	8.78	21,780	.59	3.74×10^6	2.05
6-12	54.2	2.08	22.18	5,690	.43	1.39×10^6	1.42
6-13	53.5	1.80	33.45	--	--	--	--

LOG OF ROCK PROFILE

TOP OF ROCK ELEV 77.5'

ELEV IN FEET



LIGHT GRAY TO BLACK DOLOMITE, MANY SOLUTION CAVITIES AND FILLINGS, STYLOLITIC STRUCTURES AND PARTINGS, CHERT ZONES THROUGHOUT THE ENTIRE INTERVAL

WHITE AND GRAY MOTTLED CHERT

LIGHT GRAY TO BLACK DOLOMITE

WHITE AND GRAY MOTTLED CHERT

DOLOMITE - SILTSTONE - MINOR VUGS AND SHALYLIKE STRUCTURES THROUGHOUT INTERVAL

E.O.B. 67.5'

xxxxxxxx Fracture Zone

SAMPLE NO.	ELEV IN FEET	DRY BULK SP GRAV	POROSITY %	UNCONFINED COMPRESSION TEST DATA			
				UNCONFINED COMPRESSIVE STRENGTH, PSI	DEFORMATION AT FAILURE, %	TANGENT MODULUS AT 50% ULTIMATE STRENGTH, PSI	$\frac{L}{D}$ RATIO
7-1	76.4	2.73	1.53	14,550	.47	8.45×10^6	1.67
7-2	75.4	2.62	5.65	4,760	.45	9.35×10^5	1.90
7-3	74.5	2.77	1.97	9,240	.29	3.69×10^6	2.13
7-4	73.5	2.75	0.80	NO TEST	--	--	--
7-5	73.0	2.48	6.20	10,650	.29	3.82×10^6	2.12
7-6	71.5	2.27	12.92	15,240	.44	5.52×10^6	1.91
7-7	70.9	2.35	10.07	10,980	.24	2.82×10^6	2.02
7-8	70.3	2.11	19.75	2,940	.28	9.27×10^5	2.15
7-9	69.2	2.65	6.19	2,340	.22	7.85×10^5	2.16
7-10	68.6	2.22	19.35	1,860	.19	1.12×10^6	1.94
7-11	68.1	1.91	28.84	1,700	.28	5.71×10^5	1.73

WATER LEVEL IN CASING: Elev 103.3'
RECOVERY: 100%
39% based on cores 4" or longer (32% 1st 5', 46% 2nd 5')

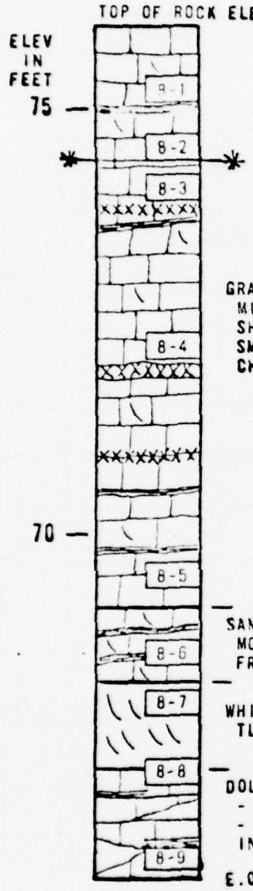
BORING DATA:

NUMBER: RCB-7
DATE OF BORING: November, 1971
LOCATION: Sta 249+00, 124'Rt of Construction ℄
GROUND ELEVATION: 144.3 ft
MADE BY: J. P. McGuire, Geophysical Unit
GEOLOGICAL LOGS BY: Geophysical Unit Geologists

Project 82122
PROPOSED I-96 (JEFFRIES FWY) THROUGH OAK YARD, CITY OF DETROIT WAYNE COUNTY, MICHIGAN

LOG OF ROCK PROFILE

TOP OF ROCK ELEV 76.0'



GRAY TO BLACK DOLOMITE, SHALY ZONES, SHALYLIKE PARTINGS, SMALL NODES OF CHERT

SAME AS ABOVE WITH MORE CHERT AND SHALE FRAGMENTS

WHITE AND GRAY MOTTLED CHERT

DOLOMITE - SILTSTONE - SHALYLIKE MINERAL - BLACK, THROUGHOUT INTERVAL

E.O.B. 66.0'

xxxxxxxx Fracture Zone

——— Water return loss

SAMPLE NO.	ELEV IN FEET	DRY BULK SP GRAV	POROSITY %	UNCONFINED COMPRESSION TEST DATA			
				UNCONFINED COMPRESSIVE STRENGTH, PSI	DEFORMATION AT FAILURE, %	TANGENT MODULUS AT 50% ULTIMATE STRENGTH, PSI	L/D RATIO
8-1	75.2	2.75	2.33	17,110	.28	4.95 x 10^6	2.19
8-2	74.5	2.66	5.79	4,070	.18	1.24 x 10^6	2.03
8-3	74.0	2.69	5.20	4,490	.29	1.86 x 10^6	2.12
8-4	72.2	2.81	0.33	21,310	.28	5.11 x 10^6	2.18
8-5	69.5	2.83	0.41	23,040	.52	5.23 x 10^6	2.21
8-6	68.6	2.42	11.69	5,640	.12	3.21 x 10^6	2.08
8-7	68.0	2.32	11.25	21,450	.50	3.46 x 10^6	2.16
8-8	67.2	2.41	8.16	28,040	.73	3.60 x 10^6	2.15
8-9	66.2	1.86	28.33	3,320	.22	9.95 x 10^6	2.20

WATER LEVEL IN CASING: Elev 99.9'

RECOVERY: 100%

38% based on cores 4" or longer (33% 1st 5', 43% 2nd 5')

BORING DATA:

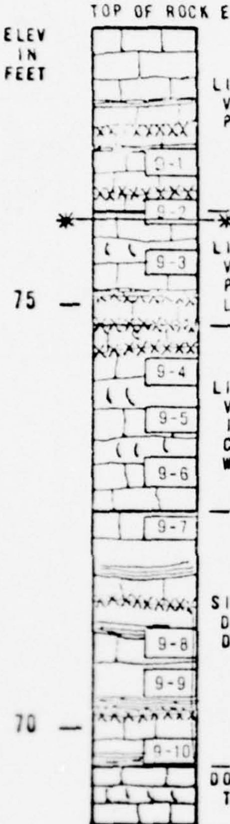
NUMBER: RCB-8
DATE OF BORING: November, 1971
LOCATION: Sta 251+00, 126'Lt of Construction ℄
GROUND ELEVATION: 144.4 ft
MADE BY: J. P. McGuire, Geophysical Unit
GEOLOGICAL LOGS BY: Geophysical Unit Geologists

Project 82122
PROPOSED I-96 (JEFFRIES FWY) THROUGH
OAK YARD, CITY OF DETROIT
WAYNE COUNTY, MICHIGAN

LOG OF ROCK PROFILE

TOP OF ROCK ELEV 78.3'

ELEV IN FEET



LIGHT GRAY DOLOMITE, VUGS, SOME SHALE PARTINGS

LIGHT GRAY DOLOMITE, VUGS, SOME SHALE PARTINGS, CHERT LAYERS

LIGHT GRAY DOLOMITE, VUGS, INTERBEDDED AND INTERMIXED WITH CHERT, MANY ZONES WITH CHERT NODULES

SILTSTONE, SHALES AND DOLOMITE - INTERBEDDED

DOLOMITE AND CHERT INTERBEDDED

E.O.B. 68.9'

xxxxxxxx Fracture Zone

* ——— * Water return loss

SAMPLE NO.	ELEV IN FEET	DRY BULK SP GRAV	POROSITY %	UNCONFINED COMPRESSION TEST DATA: UNCONFINED COMPRESSIVE STRENGTH, PSI	DEFORMATION AT FAILURE, %	TANGENT MODULUS AT 50% ULTIMATE STRENGTH, PSI	L/D RATIO
9-1	76.7	2.77	2.08	NO TEST			
9-2	76.1	2.77	1.61	11,210	.29	4.55×10^6	2.05
9-3	75.5	2.48	6.27	NO TEST			
9-4	74.2	2.35	14.06	6,100	.33	2.16×10^6	1.82
9-5	73.7	2.20	16.27	NO TEST			
9-6	73.1	2.67	4.94	NO TEST			
9-7	72.4	1.92	28.00	2,790	.29	1.04×10^6	1.69
9-8	71.0	1.84	30.63	NO TEST			
9-9	70.6	1.74	34.74	1,100	.34	3.45×10^5	1.79
9-10	69.7	2.51	8.36	NO TEST			

WATER LEVEL IN CASING: Elev 106.9'
RECOVERY: 97%
33% based on cores 4" or longer (32% 1st 5', 34% 2nd 4.4')

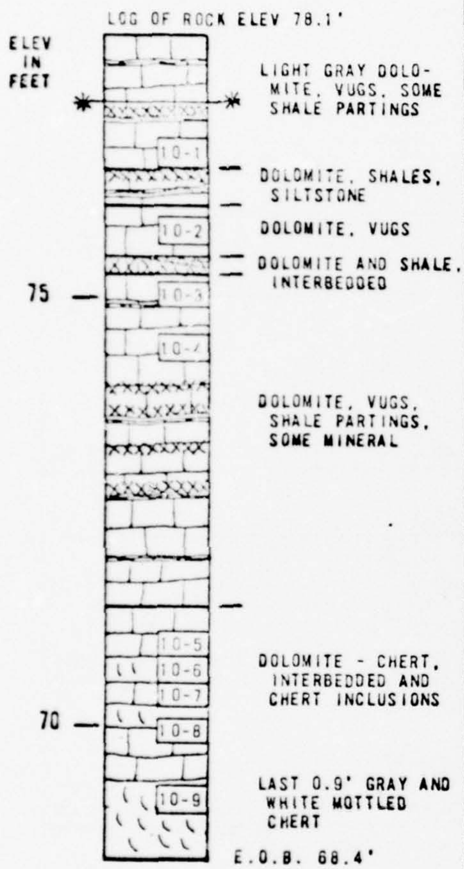
BORING DATA:

NUMBER: RCB-9
DATE OF BORING: October, 1971
LOCATION: Sta 253+00, 110'Rt of Construction ℄
GROUND ELEVATION: 143.4 ft
MADE BY: J. P. McGuire, Geophysical Unit
GEOLOGICAL LOGS BY: Geophysical Unit Geologists

Project 82122

PROPOSED I-96 (JEFFRIES FWY) THROUGH OAK YARD, CITY OF DETROIT WAYNE COUNTY, MICHIGAN

LOG OF ROCK PROFILE



xxxxxxxx Fracture Zone

—— Water return loss

SAMPLE NO.	ELEV IN FEET	DRY BULK SP GRAV	POROSITY %	UNCONFINED COMPRESSION TEST DATA: UNCONFINED COMPRESSIVE STRENGTH, PSI	DEFORMATION AT FAILURE, %	TANGENT MODULUS AT 50% ULTIMATE STRENGTH, PSI	L/D RATIO
10-1	76.7	2.74	2.63	NO TEST			
10-2	75.8	2.75	3.38	9,630	.34	2.63×10^6	1.78
10-3	75.1	2.66	0.51	NO TEST			
10-4	74.5	2.80	0.25	9,480	.46	2.44×10^6	2.11
10-5	71.0	2.74	2.46	NO TEST			
10-6	70.7	2.30	10.68	8,640	.45	2.28×10^6	2.17
10-7	70.4	2.39	8.51	NO TEST			
10-8	70.0	2.60	5.51	6,540	.28	2.21×10^6	2.18
10-9	69.2	2.38	12.89	NO TEST			

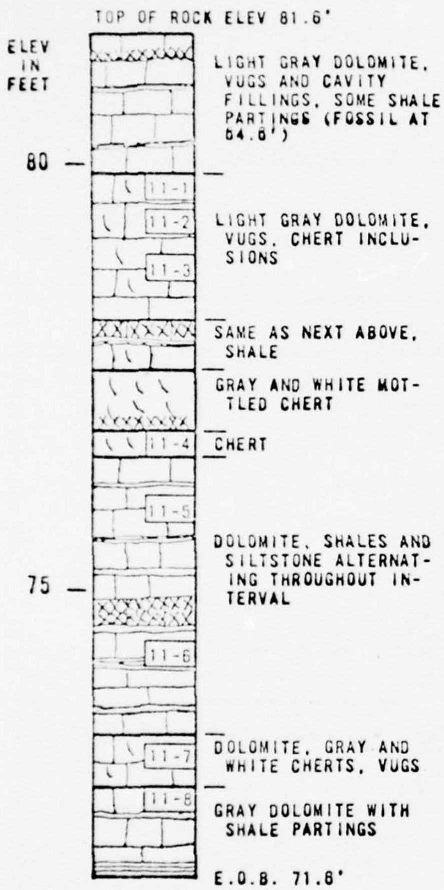
WATER LEVEL IN CASING: Not recorded
RECOVERY: 100%
33% based on cores 4" or longer (27% 1st 5', 40% 2nd 4.7')

BORING DATA:

NUMBER: RCB-10
DATE OF BORING: December, 1971
LOCATION: Sta 255+00, 126'Lt of Construction ℄
GROUND ELEVATION: 144.3 ft
MADE BY: J. P. McGuire, Geophysical Unit
GEOLOGICAL LOGS BY: Geophysical Unit Geologists

Project 82122
PROPOSED I-96 (JEFFRIES FWY) THROUGH
OAK YARD, CITY OF DETROIT
WAYNE COUNTY, MICHIGAN

LOG OF ROCK PROFILE



xxxxxxxx Fracture Zone

SAMPLE NO.	ELEV IN FEET	DRY BULK SP GRAV	POROSITY %	UNCONFINED COMPRESSION TEST DATA			
				UNCONFINED COMPRESSIVE STRENGTH, PSI	DEFORMATION AT FAILURE, %	TANGENT MODULUS AT 50% ULTIMATE STRENGTH, PSI	$\frac{L}{D}$ RATIO
11-1	79.7	2.58	6.05	NO TEST			
11-2	79.4	2.39	8.51	11,120	.23	3.93×10^6	2-12
11-3	78.8	2.48	5.80	NO TEST			
11-4	76.7	2.44	7.33	5,000	.36	1.69×10^6	2.00
11-5	76.0	2.33	14.53	NO TEST			
11-6	74.2	1.84	28.87	1,800	.79	2.83×10^5	1.84
11-7	73.0	2.36	9.85	NO TEST			
11-8	72.5	2.73	2.41	22,230	.52	4.63×10^6	1.86

WATER LEVEL IN CASING: Elev 105.6'
RECOVERY: 100%
27% based on cores 4" or longer (22% 1st 5', 32% 2nd 5')

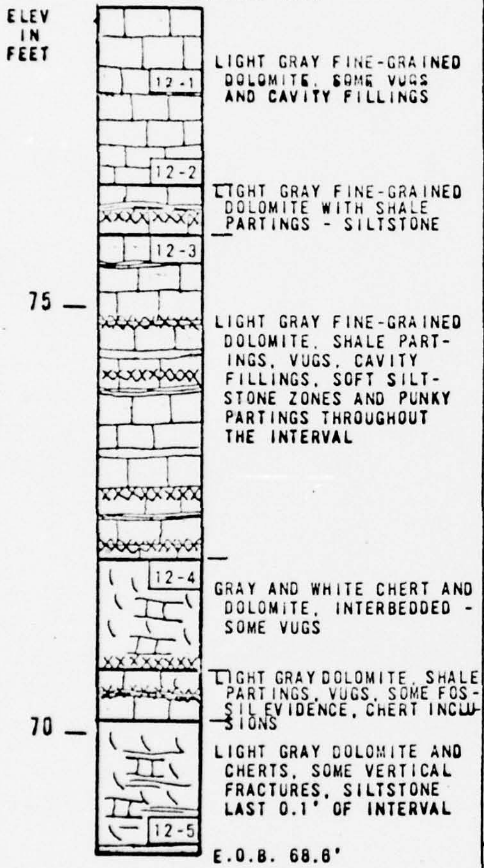
BORING DATA:

NUMBER: RCB-11
DATE OF BORING: December, 1971
LOCATION: Sta 257+00, 126'Rt of Construction ℄
GROUND ELEVATION: 144.6 ft
MADE BY: J. P. McGuire, Geophysical Unit
GEOLOGICAL LOGS BY: Geophysical Unit Geologists

Project 82122
PROPOSED I-96 (JEFFRIES FWY) THROUGH
OAK YARD, CITY OF DETROIT
WAYNE COUNTY, MICHIGAN

LOG OF ROCK PROFILE

TOP OF ROCK ELEV 78.8'



E.O.B. 68.8'

xxxxxxxx Fracture Zone

SAMPLE NO.	ELEV IN FEET	DRY BULK SP GRAV	POROSITY %	UNCONFINED COMPRESSION TEST DATA			
				UNCONFINED COMPRESSIVE STRENGTH, PSI	DEFORMATION AT FAILURE, %	TANGENT MODULUS AT 50% ULTIMATE STRENGTH, PSI	$\frac{L}{D}$ RATIO
12-1	77.7	2.74	2.31	12,060	.41	3.90×10^6	2.05
12-2	76.6	2.67	5.20	NO TEST			
12-3	75.7	2.80	0.65	NO TEST			
12-4	71.9	2.51	5.31	15,190	.23	4.67×10^6	2.12
12-5	68.9	2.39	12.49	4,110	.24	2.34×10^6	2.02

WATER LEVEL IN CASING: Elev 99.4'

RECOVERY: 100%

24% based on cores 4" or longer (26% 1st 5', 22% 2nd 5')

BORING DATA:

NUMBER: RCB-12
DATE OF BORING: December, 1971
LOCATION: Sta 259+00, 125'Lt of Construction ₵
GROUND ELEVATION: 141.9 ft
MADE BY: J. P. McGuire, Geophysical Unit
GEOLOGICAL LOGS BY: Geophysical Unit Geologists

Project 82122
PROPOSED I-96 (JEFFRIES FWY) THROUGH
OAK YARD, CITY OF DETROIT
WAYNE COUNTY, MICHIGAN

APPENDIX D

ABSTRACT OF GEOLOGIC AND HYDROLOGIC STUDIES OF THREE AREAS IN SOUTHEASTERN MICHIGAN

ABSTRACT

OF

GEOLOGIC AND HYDROLOGIC STUDIES OF THREE AREAS IN SOUTHEAST MICHIGAN

An Administrative Report of the
United States Department of the Interior
Geological Survey, Water Resources Division

By

William B. Allen, William B. Fleck and Stuart D. Hansen
25 January 1972

Summarized by the Detroit District Corps of Engineers

A 25 January 1972 Administrative Report entitled "Geologic and Hydrologic Studies of Three Areas in Southeast Michigan," written by Messrs. W. B. Allen, W. B. Fleck, and S. D. Hansen of the U.S. Department of the Interior's Geological Survey Water Resources Division is available in the Detroit District Corps of Engineers' office. That document is summarized here to provide additional geologic information to the reader. If access to this complete report is desired, the report may be reviewed in the Detroit District, Corps of Engineers offices, at 150 Michigan Avenue in Detroit, Michigan.

GEOLOGIC AND HYDROLOGIC STUDIES
OF THREE AREAS OF
SOUTHEASTERN MICHIGAN

As an initial step in obtaining the necessary geologic and hydrologic information for the Southeastern Michigan Wastewater study, three areas in Southeastern Michigan were selected for a detailed examination by the U. S. Geological Survey. These areas, shown on the accompanying location map, are as follows:

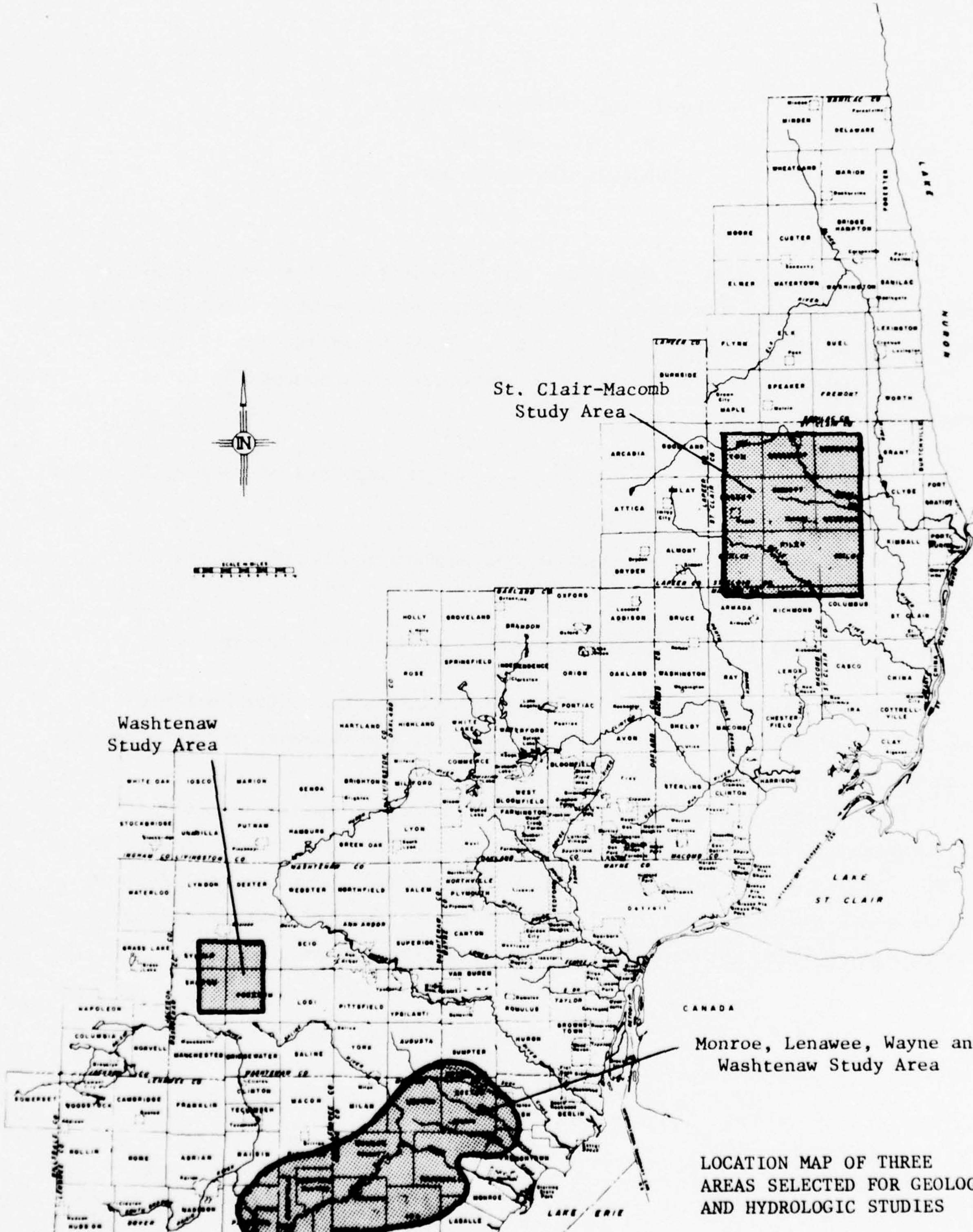
(1) An area southwest of Detroit, covering portions of Monroe, Lenawee, Washtenaw and Wayne Counties.

(2) An area north of Detroit in the western part of St. Clair and adjacent Macomb Counties.

(3) An area west of Detroit in southwest Washtenaw County.

For each of these areas, this report describes the major geologic features that determine groundwater reservoirs, the movement of water through the reservoirs, and the quality of the water.

The data for the report were gathered through a review of geologic literature and field research during the period from May through August in 1971. Eighteen test wells were drilled at selected locations in the three study areas to obtain additional geologic data. The following sections interpret the data obtained in each of these three areas.



LOCATION MAP OF THREE AREAS SELECTED FOR GEOLOGIC AND HYDROLOGIC STUDIES

MONROE, LENAWEE, WAYNE AND WASHTENAW STUDY AREA

Physical Features

This approximately 400 square mile area, is characterized by low relief, ranging from 600 to 750 feet above mean sea level. Soils generally are clayey, but may be locally sandy. The area is drained by the rivers of the River Raisin basin, along with Stony, Sandy, and Swan Creeks. Glacial deposits of clay with areas of till, sand and gravel underlie the surface with thickness ranging from 0 to 190 feet. These deposits overlie bedrock composed of dolomite, limestone, sandstone and shale.

Surface Deposits

Surface deposits in this area are the glacial lake clays and sands, which cover about 80 percent of the land surface. Till plains, moraines, and outwash sands cover about 15 percent of the land surface in the western part of the area. Alluvial deposits, not directly associated with glacial processes, are found along the major stream valleys.

Bedrock

Bedrock in the study area is sedimentary rock. Principal types are sandstone, shale, dolomite and limestone; minor types are salt, gypsum and anhydrite. Because the bedrock is part of the southeast rim of a structural basin, the rocks dip northwestward and are older from northwest to southeast, only the bedrock types immediately beneath the drift were considered in this report, since they are weathered and fractured, and hence have openings that increase their permeability. These bedrock aquifers provide water for about 90 percent of the wells in the study area.

Aquifers and Aquicludes

Although bedrock aquifers supply most of the wells in this study area (essentially the River Raisin basin), wells in drift supply water from morainic and outwash areas. Bedrock aquifers include limestones, dolomites, and sandstones. Shale formations, such as the Coldwater and Antrim shales yield little or no water. Drift aquifers are beds of sand and gravel in the morainic and outwash areas in Lenawee county. In very few places, permeable drift overlies permeable rock, with a continuous aquifer resulting. In most of this study area, the drift overlying the bedrock is an aquiclude of clay and till. Much of the water in the bedrock is under confined conditions of occurrence. Buried sands and gravels (outwash) within glacial till deposits

also represent confined conditions of ground water occurrence, whereas, surface outwash deposits constitute the water-table, or unconfined, aquifers of the area.

Water Table

The water table generally follows the slope of the land surface, declining in elevation from west to east. Local variations occur, however, at or near streams where groundwater discharges to the streams. The aquifers (both shallow drift and bedrock) are recharged through infiltration of precipitation and surface water, with the rate of infiltration depending on the amount and intensity of rainfall, the season of the year, the rate of evapotranspiration, and the hydraulic conductivity of the materials through which the water percolates. In this area, recharge is greatest in April and May and least in summer when evapotranspiration rates are high. Recharge is generally highest in permeable outwash deposits and in the sandy lakebeds in the western part of the area. Recharge in areas of till and clay lake beds is generally very low.

Groundwater Quality

Groundwaters in this study area may be classified into several chemical types. The groundwaters of the bedrock in the southeastern third of the area are predominantly of a calcium-sulfate type with dissolved solids contents of up to 2000 mg/l. Along the extreme southeast margin, the waters have a lower dissolved solids content and are of a calcium magnesium bicarbonate type. Through the central part of the study area, the groundwaters have a dissolved solids content of less than 500 mg/l. Bicarbonate is the principal anion; the principal cations are sodium or calcium.

Surface Water Quality

Samples of streams in the study area were collected in 1970 and 1971. Based on that data, the following conclusions were reached. The dissolved-solids content of the surface water ranges from 350 to 2000 mg/l. Although complete chemical analyses were not conducted, the data indicated that the principal dissolved solids at most locations are calcium, magnesium, bicarbonate, and sulfate. The nitrate content, which is somewhat higher than in most natural waters, ranged from 0 to 16 mg/l. The higher nitrate values may be the result of waste discharge to streams.

ST. CLAIR AND MACOMB STUDY AREA

Physical Features

This site has an approximate area of 220 square miles. The topography is relatively flat, the area exhibiting a maximum relief of 230 feet. Elevations range from 850 feet above mean sea level along the west margin to 620 feet along the east margin. On the west margin lies a belt of low morainic hills. The area is underlain by glacial drift composed on clay and till interbedded with layers of sand and gravel. The drift, ranging in thickness from about 100 feet to 350 feet overlies bedrock of shale and sandstone.

Surface Deposits

An extensive till plain overlies much of the area; it is, however, a varied mix of lacustrine clay, alluvium, outwash, and lacustrine and delta sand. The lacustrine clays include thick sequences of clay and silt, while the till plains are underlain by clay and silt containing sand and gravel. Both the clays and tills have extremely low hydraulic conductivity. The lacustrine and delta sand deposits, exposed in the western part of the study area, form the principal aquifer. This aquifer typically is sand, grading locally into gravel or silt.

Bedrock

Bedrock units underlying the glacial drift are the Coldwater, Sunbury, and Berea Formations. The Berea Sandstone and Sunbury Shale underlie the drift only in a very small area in the eastern part. The Coldwater shale underlies the drift in the rest of the area. The relief of the bedrock varies to a greater degree than that of the surface. In the southwestern part of the study area, a deeply incised preglacial valley trends eastward. Along this valley, the thickest deposits of glacial material are located.

Aquifers and Aquicludes

The principal aquifer in this study area is represented by the extensive lacustrine and deltaic sands described in the paragraph on glacial deposits. This aquifer supplies most domestic wells, and also supplies the city of Memphis. Near the western edge of the area, the aquifer is at the land surfaces where water percolates directly into it. The aquifer dips to the east under the impermeable clays and tills which act as an aquiclude.

Water Table

The water table generally slopes toward the east. Near the east edge of the area the gradient of the potentiometric surface increases, suggesting discharges from the artesian aquifer to streams and shallow aquifers. The only surface waters that have been shown to have significant contribution from groundwater, however, are portions of Mill Creek.

Groundwater Quality

Samples of groundwater were collected in August 1971 for chemical analysis. Most of the samples were taken in the lacustrine and delta sand aquifer. The groundwaters proved to be of several different chemical types. Nitrate was detected in 29 percent of the samples tested. Maximum concentration was 6.3 mg/l. Phosphorus was found in 38 percent of the samples analyzed. The maximum concentration was found to be 0.17 mg/l, expressed as phosphate. Most groundwater had an iron content exceeding the U.S. Public Health Service's (1962) Drinking Water Standard of 300 μg/l (micrograms per liter). The concentration of heavy metals was low, however.

Surface Water Quality

Samples of surface streams were collected during base flow studies in 1967 and 1971. Chemical analysis showed the dissolved solids content of surface water to be generally less than that of groundwater. The higher dissolved-solids content of Mill Creek, whose channel is incised into the groundwater aquifer, illustrates again that Mill Creek does obtain a significant contribution to its base blow from groundwater.

WASHTENAW STUDY AREA

Physical Features

The Washtenaw County study area, is about 130 square miles in size located in southwestern Washtenaw County. The topography is of rolling to hilly relief, with land surface elevations ranging from 830 to 1100 feet above mean sea level. Soils range from clayey to sandy. The northern part of the site is drained by Letts Creek, North Fork Mill Creek, and Mill Creek, all in the Huron River basin. River Raisin drains the southeastern part of the study area, with the Saline River draining the east part.

Surface Deposits

Glacial deposits in this area are composed of silts, clays, sands, gravel and boulders. Thickness of these deposits ranges from 50 to 250 feet. The

southeastern portion of the area has morainic deposits varying from clay till with large amounts of sand and gravel to clay till with small amounts of gravel. The northwestern part of this study area is underlain by morainic and outwash deposits. The central area is a till plain underlain by clay till. Material comprising till plains is generally similar to those in the morainal area.

Bedrock

The northern two-thirds of the western half of the study area is underlain by the Michigan and Marshall sandstones. The rest of the area is underlain by the Coldwater shale. While the Michigan and Marshall sandstones are permeable, the Coldwater shale is not. Bedrock surface is above 900 feet mean sea level in the western part of the site. The bedrock surface slopes steeply toward a major bedrock valley trending southeastward through the central portion of the study area. There is also a shallow bedrock valley trending eastward in the study area's northeast corner.

Aquifers and Aquicludes

In this Washtenaw County study area, the glacial deposits are the primary source of groundwater, although some water is obtained from bedrock. The glacial drift aquifers are permeable sand and gravel deposits. These deposits occur as continuous bodies and as small lenses. Although the clay content of some of the soils may be locally high, there are no extensive aquicludes in this area. Wells for domestic supply have been driven into the underlying Michigan and Marshall sandstones. No wells are known to obtain potable water from the Coldwater shale.

Water Table

The water table slopes generally eastward and toward the major streams as does the surface topography. Aquifers in the till plain seem to be poorly interconnected and of small areal extent. The aquifers in the Michigan and Marshall sandstones seem to exhibit the presence of an overlying "leaky aquiclude" (i.e., the aquiclude is not impermeable, allowing water to infiltrate in spots to the sandstone formation). The village of Chelsea, miles north of the Wastenaw County study area, obtains its water supply from wells in sand and gravel lenses in till. While the reported capacities of wells in the Michigan and Marshall sandstones are in the same range as wells in the glacial drift, it is possible that large diameter wells penetrating

these formations for more than 100 feet may yield large supplies of water.

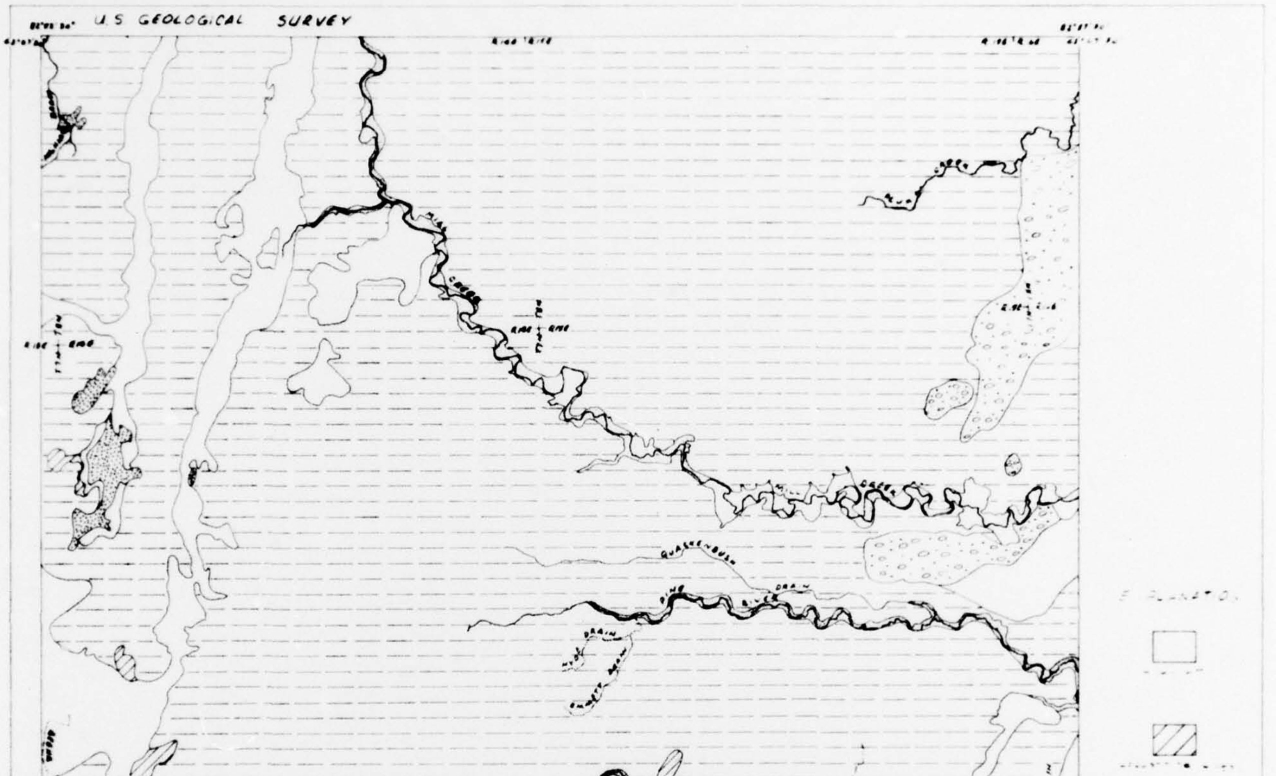
Water Quality

Water quality data were obtained in this study area to establish a base of background information. Water from the bedrock and the glacial deposits is of a calcium-magnesium bicarbonate type, with dissolved solids contents ranging from about 250 to 544 mg/l. The chemical characteristics of groundwater and the surface water are similar, with dissolved solids contents in surface streams ranging from 170 to 509 mg/l. This similarity illustrates the close relationship that exists between the aquifers and the streams in the study area. Nitrate concentrations in the groundwaters were generally less than 0.1 mg/l. Nitrate concentrations in the surface waters ranged from 0 to 6.0 mg/l; however, more than half the surface waters contained less than 1 mg/l. Phosphorus content of groundwaters was low, ranging from 0 to 0.31 mg/l. Surface water phosphorus content was somewhat higher, ranging from 0.03 to 1.7 mg/l.

SUMMARY

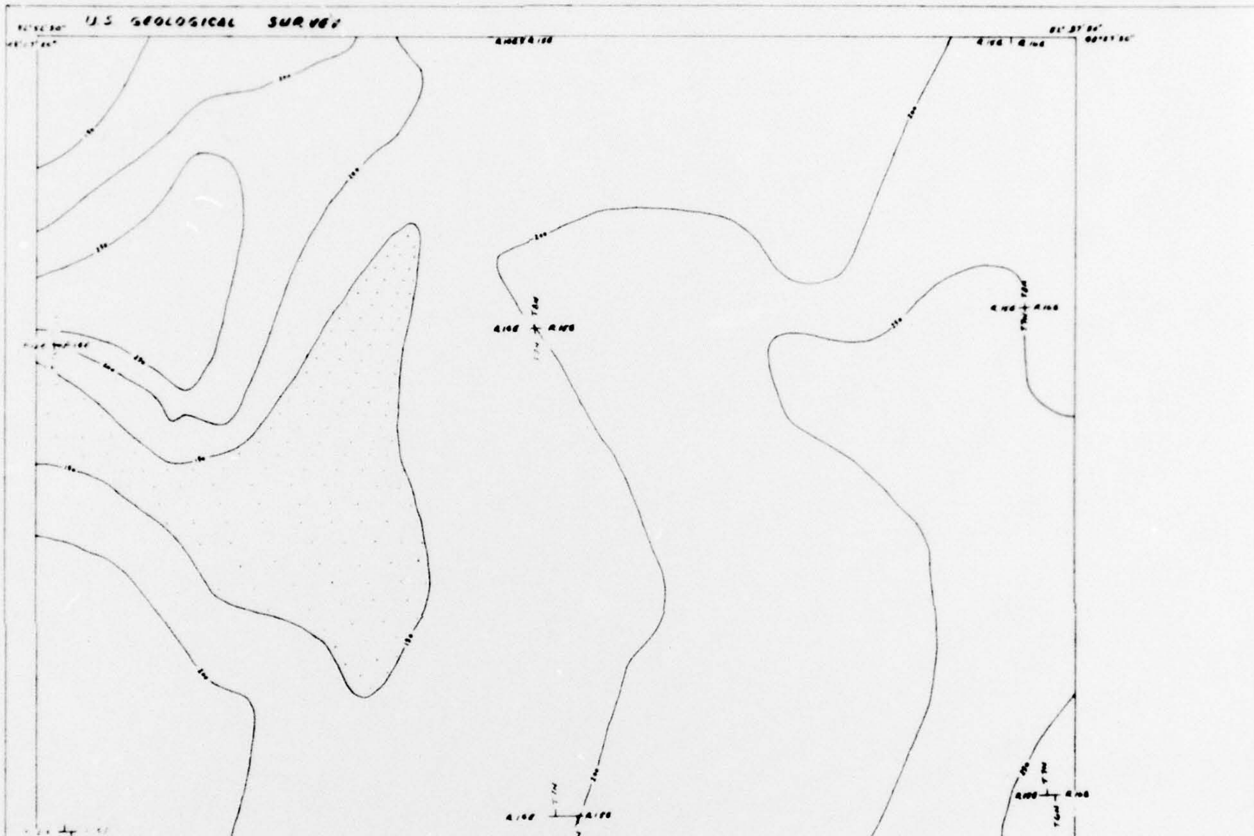
The following table summarizes some of the major facts about the three study areas.

	Monroe, Lenawee, Wayne and Washtenaw study area	St. Clair and Macomb study area	Washtenaw study area
Physical features	A 405 square mile area of mostly flat terrain, altitudes range from 600 to 750 feet above mean sea level.	A 219 square mile area of mostly flat terrain, altitudes range from 620 to 850 feet above mean sea level.	A 130 square mile area of rolling to hilly terrain, altitudes range from 830 to 1,100 feet above mean sea level.
Geology	Surface deposits chiefly glacial lake clays and sands, Bedrock is chiefly sandstone, limestone and shale.	Surface deposits chiefly lake clays, sands and till. Bedrock is sandstone in small area in east, shale in rest of area.	Surface deposits mostly permeable or semipermeable moraines, outwash and till plains. Bedrock is sandstone in west, shale in rest of area.
Principal aquifers	Major aquifers in bedrock. Few wells in drift. Drift acts as aquiclude over most of area.	Major aquifer is a sand unit which is continuous over 80 percent of area. Lake clays and till over sand unit are aquiclude.	Major aquifers are sand and gravel deposits which occur over most of area. Bedrock supplies a few wells in west.
Occurrence of ground water	Recharge of bedrock aquifers through drift greatest in west part where relatively permeable moraine and outwash occur. Recharge to bedrock through aquiclude is very small.	Recharge to major sand aquifers is chiefly in sandy area at west edge. Recharge through aquiclude over most of area to east is very small.	Recharge occurs where permeable materials are at surface. Recharge probably is much greater than in other areas.
Quality of water	Dissolved-solids content of ground water ranges from about 150 to about 3,500 mg/1; surface water from 350 to about 2,000 mg/1.	Dissolved-solids content of ground water ranges from about 200 to about 750 mg/1; surface water generally has lower dissolved-solids than ground water.	Dissolved-solids content of ground water ranges from about 250 to about 550 mg/1. Surface water quality is similar to ground water.



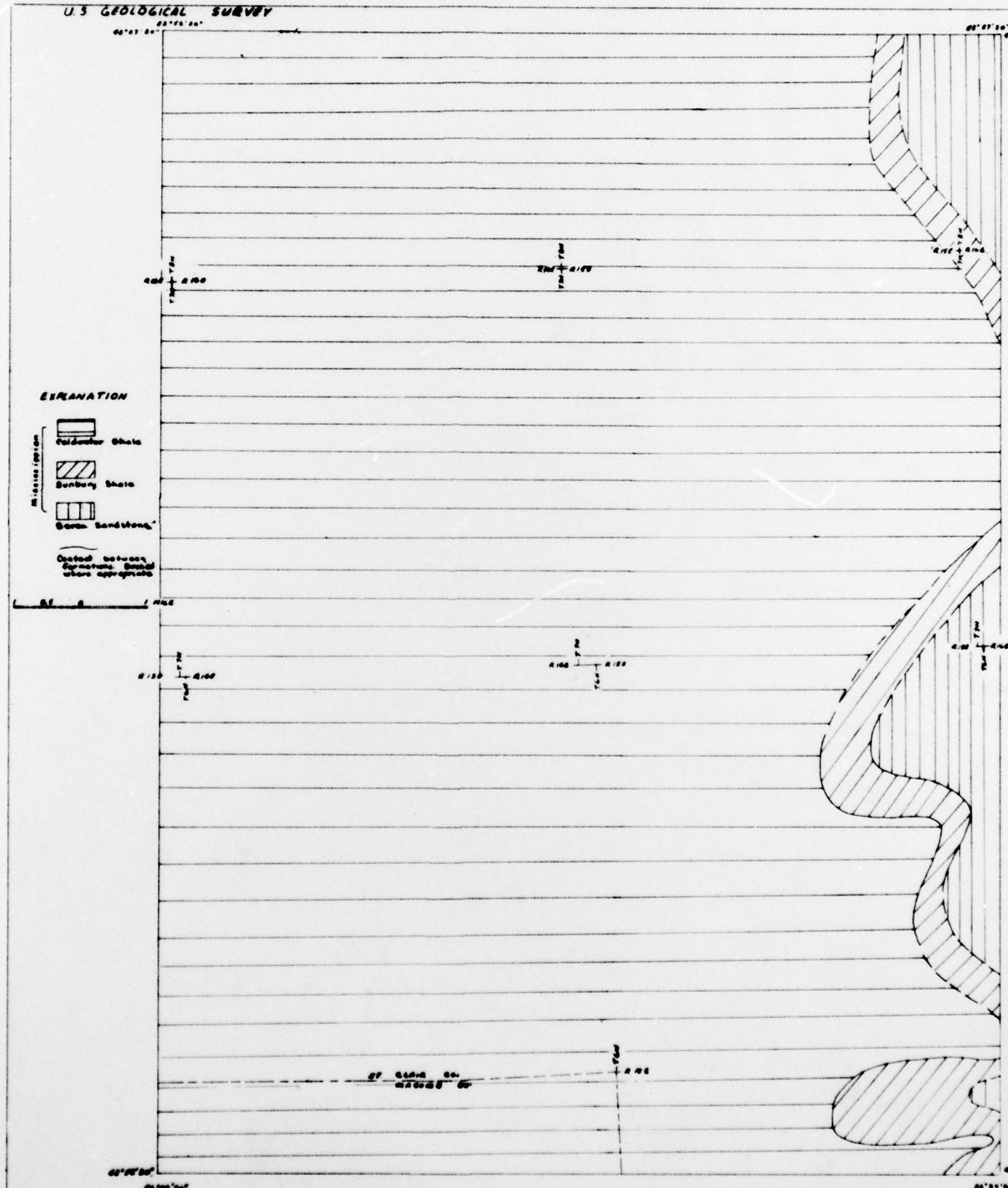
SURFACE GEOLOGY OF PARTS OF MACOMB AND ST. CLAIR COUNTIES

APPENDIX E-1



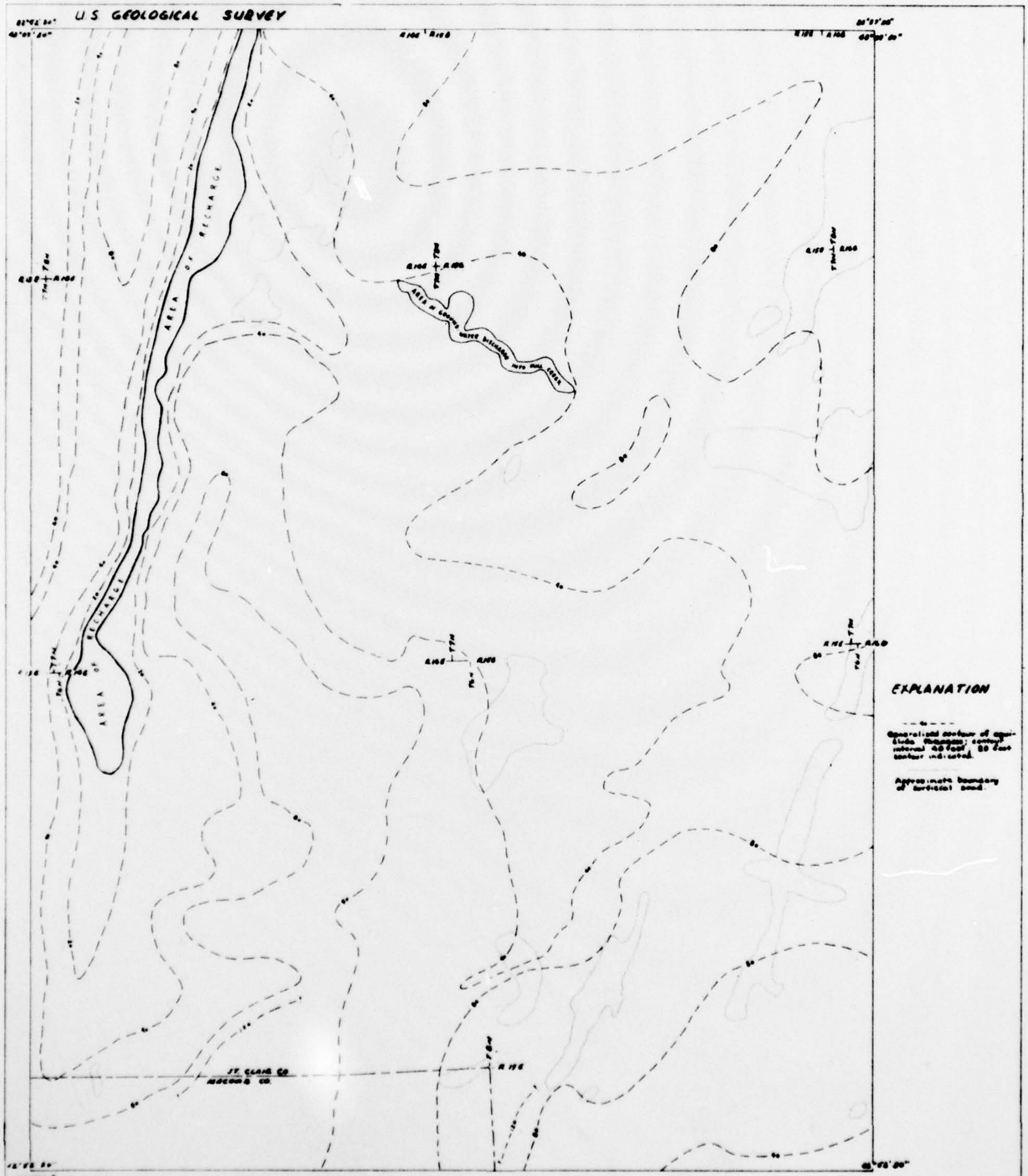
T-CK-ESS OF GLACIAL DRIFT IN PARTS OF MA-COMB AND ST. CLAIR COUNTIES

APPENDIX E-2



BEDROCK GEOLOGY OF PARTS OF MACOMB AND ST. CLAIR COUNTIES

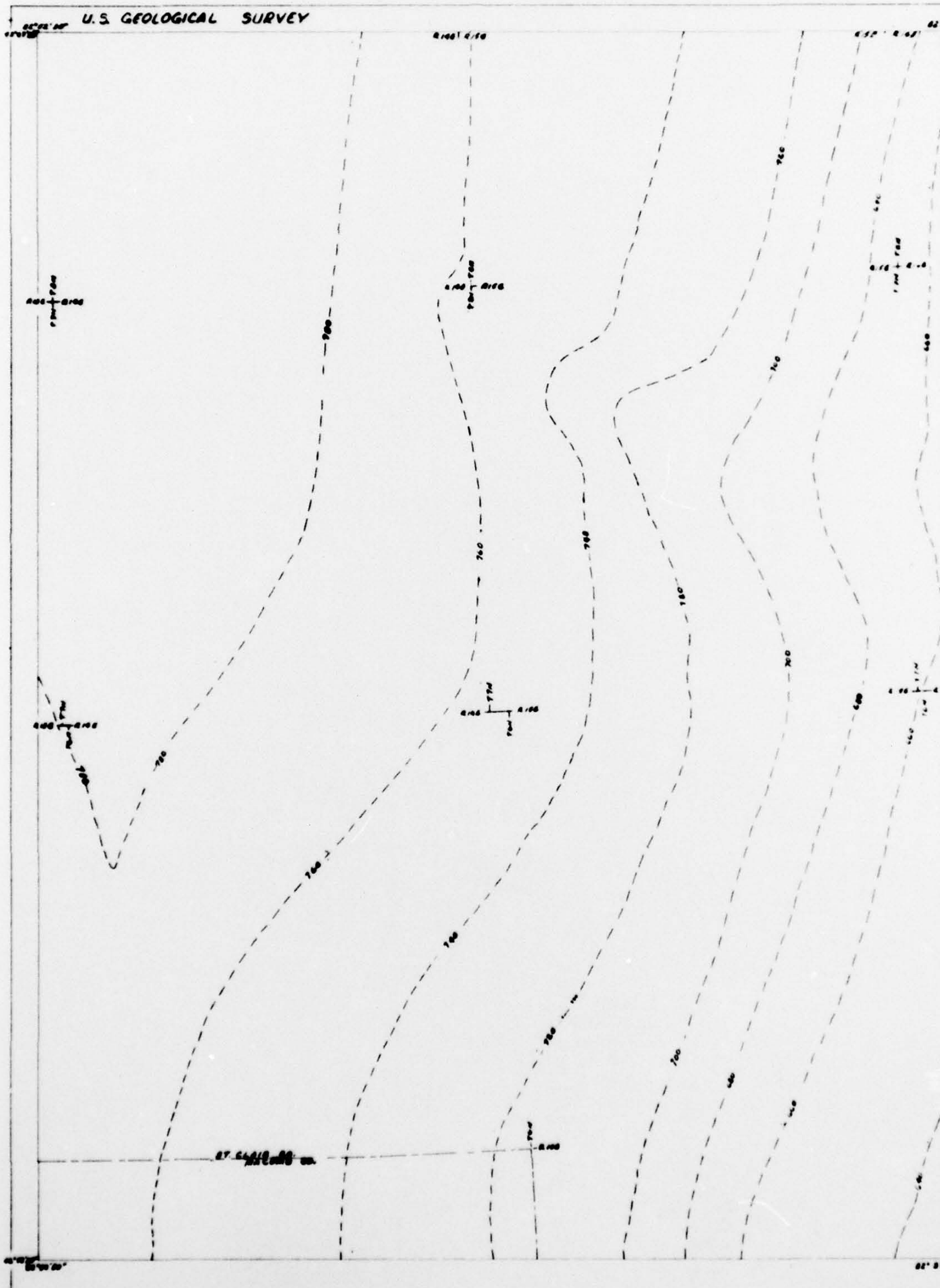
APPENDIX E-3



AQUICLUDE THICKNESS OF PARTS OF MACOMB AND ST. CLAIR COUNTIES

APPENDIX E-4

U.S. GEOLOGICAL SURVEY



EXPLANATION

Contour interval 20 feet

Datum is mean sea level

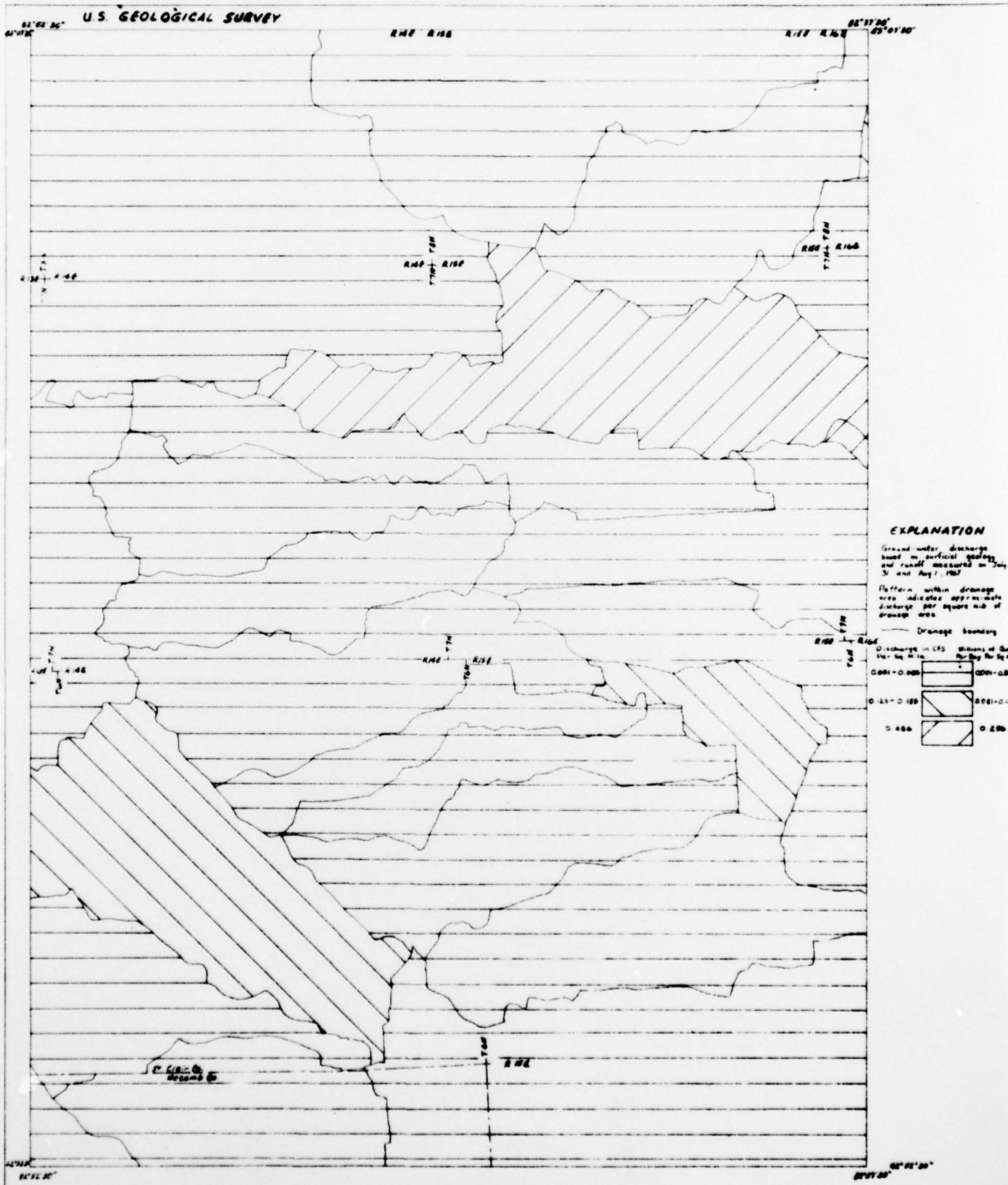
Land-surface elevations of well heads estimated from U.S. Geological Survey topographical maps

Data obtained from drillers water-well logs on file with the Michigan Geological Survey

Contours dashed where approximated

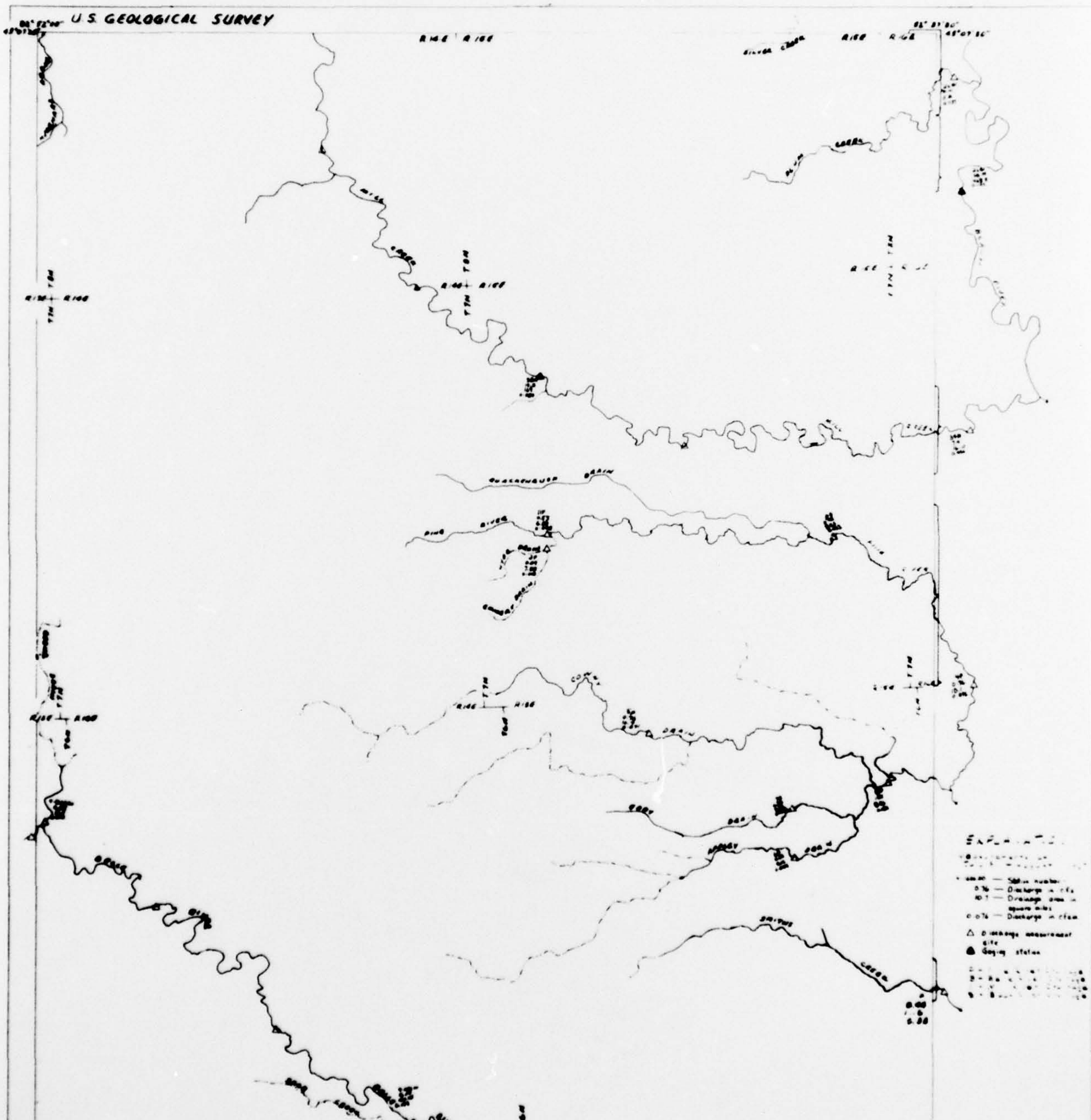
GENERALIZED POTENTIOMETRIC WATER LEVEL FOR PARTS OF MACOMB AND ST CLAIR COUNTIES

APPENDIX E-5



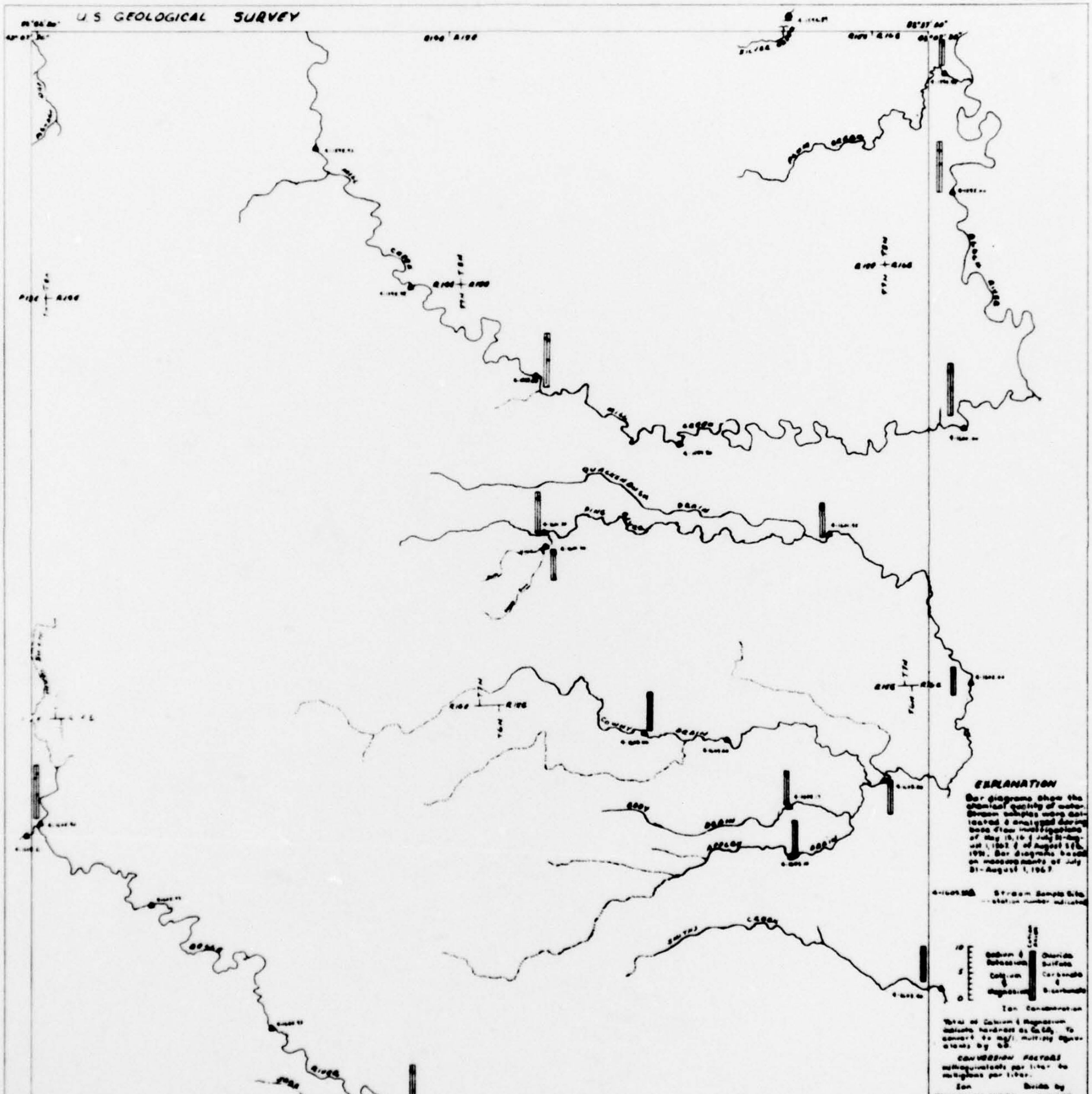
ESTIMATED GROUNDWATER DISCHARGE OF PARTS OF MACOMB AND ST. CLAIR COUNTIES

APPENDIX E-6



BASIC DATA FOR BASEFLOW ANALYSIS OF PARTS OF MACOMB AND ST. CLAIR COUNTIES

APPENDIX E-7



WATER QUALITY OF STREAMS IN PARTS OF MACOMB AND ST. CLAIR COUNTIES

APPENDIX E-8